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Proceedings of the I·R·E

A Journal of Communications and Electronic Engineering

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Volume 41 Number 12

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The Institute of Radio Engineers

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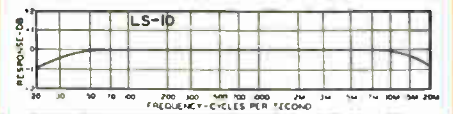
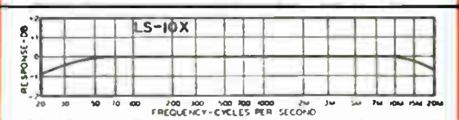
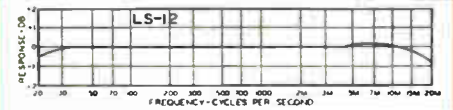
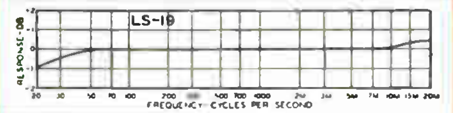
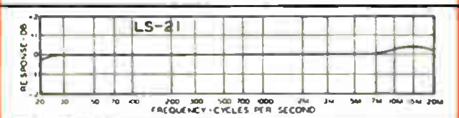
The ever increasing use of wide range equipment for broadcast service has reached the point where the major limiting factor is the frequency range of the transformers employed. UTC Linear Standard components represent the closest approach to the ideal transformer from the standpoint of uniform frequency response, low wave form distortion, high efficiency, thorough shielding, and dependability. Typical LS units are described below.

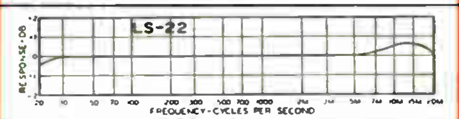


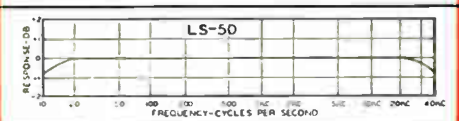


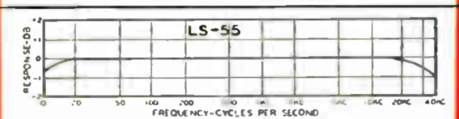


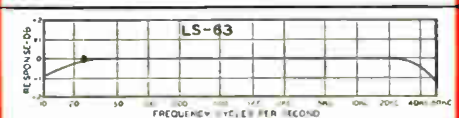


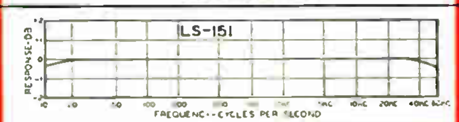












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INPUT TRANSFORMERS

Case Size	LS-1	LS-2
Length	3⅛″	4 7/16″
Width	2⅝″	3½″
Height	3¼″	4 3/16″

Type No.	Application	Primary Impedance	Secondary Impedance	± 1 db from	Max.† Level	Relative* hum	Unbal. DC in prim'y	Case No.	List Price
LS-10	Low impedance mike, pickup, or multiple line to grid	50, 125/150, 200, 250, 333, 500/600 ohms	60,000 ohms in two sections	20-20,000	+10 DB	−74 DB	.5 MA	LS-1	$25.00
LS-10X	As above	As above	50,000 ohms	20-20,000	+10 DB	−92 DB-Q	.5 MA	LS-1	35.00
LS-12	Low impedance mike, pickup, or multiple line to push pull grids	50, 125/150, 200, 250, 333, 500/600 ohms	120,000 ohms overall, in two sections	20-20,000	+10 DB	−74 DB	.5 MA	LS-1	28.00
LS-12X	As above	As above	80,000 ohms overall, split	20-20,000	+10 DB	−92 DB-Q	.5 MA	LS-1	35.00
LS-15X	Three isolated lines or pads to one or two grids	30, 50, 200, 250 ohms each primary	60,000 ohms overall, in two sections	20-20,000	+10 DB	−92 DB-Q	.5 MA	LS-1	37.00

INTERSTAGE AND MATCHING TRANSFORMERS

Type No.	Application	Primary Impedance	Secondary Impedance	Response	Max.† Level	Relative* hum	Unbal. DC in prim'y	Case No.	List Price
LS-19	Single plate to push pull grids like 2A3, 6L6, 300A. Split secondary	15,000 ohms	95,000 ohms; 1.25:1 each side	± 1 db 20-20,000	+12 DB	−50 DB	0 MA	LS-1	$26.00
LS-21	Single plate to push pull grids. Split pri. and sec.	15,000 ohms	135,000 ohms; 3:1 overall	± 1 db 20-20,000	+10 DB	−74 DB	0 MA	LS-1	26.00
LS-25	Push pull plates to push pull grids. Medium level. Split primary and sec.	30,000 ohms plate to plate	50,000 ohms; turn ratio 1.3:1 overall	± 1 db 20-20,000	+15 DB	−74 DB	1 MA	LS-1	32.00
LS-30	Mixing, low impedance mike, pickup, or multiple line to multiple line	50, 125/150, 200, 250, 333, 500/600 ohms	50, 125/150, 200, 250, 333, 500/600 ohms	± 1 db 20-20,000	+15 DB	−74 DB	.5 MA	LS-1	26.00
LS-33	High level line matching	1.2, 2.5, 5, 7.5 10, 15, 20, 30, 50 125, 200, 250, 333, 500/600	50, 125, 200, 250, 333, 500/600 ohms	± .2 db 20-20.000	15 watts			LS-2	30.00

OUTPUT TRANSFORMERS

Type No.	Application	Primary Impedance	Secondary Impedance	Response	Max.† Level	Relative* hum	Unbal. DC in prim'y	Case No.	List Price
LS-50	Single plate to multiple line	15,000 ohms	50, 125/150, 200, 250, 333, 500/600	± 1 db 20-20,000	+15 DB	−74 DB	0 MA	LS-1	$20.00
LS-52	Push pull 245, 250, 6V6 or 245 A prime	8,000 ohms	500, 333, 250, 200, 125, 50, 30, 20, 15, 10, 7.5, 5, 2.5, 1.2	± .2 db 25-20,000	15 watts			LS-2	35.00
LS-55	Push pull 2A3's, 6A5G's, 300A's, 275A's, 6A3's, 6L6's, 6AS7G	5,000 ohms plate to plate and 3,000 ohms plate to plate	500, 333, 250, 200, 125, 50, 30, 20, 15, 10, 7.5, 5, 2.5, 1.2	± .2 db 25-20,000	20 watts			LS-2	35.00
LS-63	Push pull 6F6, class B 46's, 6AS7G, 807-TR, 1614-TR	10,000 ohms plate to plate and 6,000 ohms plate to plate	30, 20, 15, 10, 7.5, 5, 2.5, 1.2	± .2 db 25-20,000	15 watts			LS-2	25.00
LS-151	Bridging from 50 to 500 ohm line to line	16,000 ohms, bridging	50, 125/150, 200, 250, 333, 500/600	± 1 db 15-30,000	+18 DB	−74 DB	1 MA	LS-1	27.00

The values of unbalanced DC shown will effect approximately 1.5 DB loss at 30 cycles.
* Comparison of hum balanced unit with shielding to normal uncased type. Q Multiple alloy magnetic shield.
† 6 MW as ODB reference.

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PROCEEDINGS OF THE I.R.E.®

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Reg. U. S. Pat. Off.

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Arthur V. Loughren

DIRECTOR, 1953

Arthur V. Loughren was born in Rensselaer, N. Y., on September 15, 1902. He received the B.A. and the E.E. degrees from Columbia University in 1923 and 1925, respectively.

Joining the Research Laboratory of the General Electric Co. upon graduation, Mr. Loughren spent two years concerned with the problems arising from the adaptation of vacuum tubes to circuits. A period of two and a half years in the Radio Engineering Department followed. In 1930 he transferred to the RCA Manufacturing Co. at Camden, N. J., where, successively, he was responsible for the design of tuned radio-frequency receivers, loudspeakers and phonograph pickups, as well as all factory tests and inspections. In 1934, he rejoined the General Electric Co. at Bridgeport, Conn., to work on the design of radio receivers.

In 1936 Mr. Loughren joined the laboratories of the Hazeltine Corp. He has been Engineer-in-Charge of television development, design supervisor for military equipment programs, and is now director of research and executive vice president of its subsidiary, Hazeltine Research Inc.

Mr. Loughren received the U. S. Navy, Bureau of Ships, Certificate of Commendation for Outstanding Service to the U. S. Navy during World War II for contributions to electronic development.

Mr. Loughren joined the IRE as an Associate in 1924, became a Member in 1929, a Senior Member in 1943 and a Fellow in 1944. His IRE activities have included service on Admissions, Membership, Papers Procurement, Standards, Television, and Policy Advisory, as well as Chairmanship of the Awards Committee. He has been a member also of Radio Receivers; Subcommittee on Definitions, and Standardization; Subcommittee on Vacuum Tubes. Mr. Loughren became a Director of the Institute in 1952.

His activities in other professional and industrial bodies included membership in Panels 7 and 9 of the first National Television System Committee and Panel 6 of the Radio Technical Planning Board, service as Vice Chairman of the present National Television System Committee and Chairman of its Panels 7 and 13, Chairman of the Joint Technical Advisory Committee, and service on RETMA committees.

Mr. Loughren has been awarded twenty-nine U. S. electronics patents. He is a member of Phi Beta Kappa, Sigma Xi, and Tau Beta Pi.

The Natural History of the Boffin

ROBERT WATSON-WATT

In delightfully whimsical fashion, the author of the following guest editorial discusses the important subject of operational analysis—and, more particularly, the procedures involved in designing equipment to fit the user and the condition of actual use (rather than the reverse). He who can do this job effectively is termed a "Boffin." But he who tends to do the reverse is denominated a "Back Room Bird."

With which preamble, the readers of these PROCEEDINGS are offered the pungent thoughts of a guest editorial from a leading inventor, developer, and designer of radar and electronic devices. He is a Fellow of the Institute, and Governing Director of his own organization in London, England.—*The Editor*

Soon after the end of World War II, I ventured to address the National Academy of Sciences on the subject of "The Natural History of the Boffin." It was an informal occasion and I treated the subject, as the title suggests, perhaps a little lightheartedly, but it was a serious subject nonetheless.

I feel moved to come back to the subject now, because I find so little understanding of what it takes to make a Boffin. In particular, there is some confusion about the difference between The Boffin and that adaptation of Lord Beaverbrook's, the "Back Room Boy." They are quite different creatures, although they have a lot in common. I believe it is important to our present-day defense problems to examine carefully what it is that makes a good "Back Room Boy" into a Boffin, and why there are some good "Back Room Boys" who will never be Boffins.

It is, I take it, obvious there can be no good defense science without the "Back Room Boy"; I am anxious to establish that there can be no good defense science without the Boffin.

What is he? The proud title of Boffin was first conferred on a few radar scientists by Royal Air Force officers with whom they worked in close co-operation. It is a term of respect, and admiration, but particularly a term of affection—an affection which is expressed, as is the English way, in a slightly outside-in, jocular way so that the affection and admiration may not be regarded as too demonstrative. I am not quite sure about the true origins of this name of Boffin. It certainly has something to do with an obsolete type of aircraft called the Baffin, something to do with that odd bird, the Puffin; I am sure it has nothing at all to do with that first literary "Back Room Boy," the claustrophiliac Colonel Boffin, who as you remember never overtly emerged from his back room, although his voice was clearly audible from it. It is the very essence of the Boffin that he should emerge frequently and almost aggressively from the Back Room to which, however, he must return on his missions of interpretation and inspiration. The pedigree of the Boffin has dominant strains in common with the "Back Room Boy" but they are paralleled and interwoven with strains essentially differentiating the two species. The Boffin must, it is true, be capable himself of designing scientifically and technically good devices. But he is no Boffin unless his primary activity is to ensure that such devices are matched to the conditions of use in the field. The Boffin is, in fact, a cross between the predominantly domesticated "Back Room Bird," who synthesizes devices from raw materials of his own and other people's providing, and the predominantly free-ranging observer-analyist, who formulates an operational specification in terms of the needs of the situation and the personnel concerned, thus providing an essential preliminary to the technical specification on which the "Back Room Bird" works.

The indispensable characteristics of the Boffin include an insatiable curiosity, an indomitable insistence, and an inherent indiscipline. But to these perhaps not very endearing characteristics he must add others which make him equally welcome in the laboratory, at the Staff Conference Table, and in the Sergeant's Mess, for only by gossiping around in all these places, in being as welcome on the tarmac as in the laboratory, can he carry out his mission of discussing why beautiful black boxes sometimes give disappointing results when they get to the squadron, and discovering in particular (in the only place where full knowledge exists) why some of the beautiful black boxes are hopelessly unfitted for use by the only people available to use them. I believe that his welcome in these varied habitats depends largely on his plumage, which should be of drab and uniform civilian gray, for I need not remind you that the civilian lounge suit is the only true uniform. The so-called "uniform" is designed specifically to accentuate non-uniformity and mark differences of rank and function, while the lounge suit de-emphasizes these differences. There are, of course, situations in which the Boffin bird must have protective coloration of a preferred military kind, light blue, dark blue, or brown. But even then it is most undesirable to carry any of the brightly-colored markings suggesting a difference of rank or essential status between the Boffin and those on whom he depends for his fundamental wisdoms.

The Boffin bird has a long bill with two special functions: poking into other people's business, and puncturing the more highly-colored and ornate eggs of the "Lesser Back Room Bird," which are quite inappropriate to the military scene. On the one hand the Boffin bird is a relentless hunter of gremlins, fairies, jinxes, and bugaboos; on the other, he is a kind of altruistic cuckoo, throwing out of the military nest the comparatively useless eggs of the domesticated and cagebound "Lesser Back Room Bird," and laboriously carrying to the nest the eggs of his own close kin the "Greater Back Room Bird," which alone are fitted for survival in the field.

The song of the Boffin bird has points in common with that of the nightingale: an attractively wide range of pitch, tone color and melody which is, however, liable to irritate by the monotonous process of "damnèd iteration" which is indispensable for getting the message home. The profoundest theme of his song is: "Men Matter More Than Matter." Perhaps the most widely known element in his song is that which says: "Give them the third best to go on with, the second best comes too late, the best never comes." And of course the Boffin bird must have long legs and a long neck, for while his head must sometimes be in the clouds, his feet must always be on the ground. The eggs of the Boffin are of a peculiar biconic shape; however frequently and firmly Boffin ideas are pushed aside, they roll back into the foreground; they are unbreakable because they are full of solid meat.

Do you ask for a plain language account? Here, I hope it is. The Boffin is a researcher, of high scientific competence, who has learned that a device of great technical elegance, capable of a remarkable performance in the hands of a picked crew, is not necessarily a good weapon of war. He is the instrument for building into the design provisions which depend on close analysis of the vehicle in which the device is to operate, the field conditions in which it is to operate and above all things, the competence of those who are to operate, maintain, and repair it. He alone can save us from the danger of engendering electronic dinosaurs; he alone can provide on the one hand the knowledge on which the machine can be measured to the man and on the other, the knowledge on which can be based the selection, training, and (this is important) the inspiration of the normal human beings on whom its successful use, in the end, must rest. He must have an understanding and an appreciation of these normal human beings. He can reach these only through having their confidence. He is a middleman, but he is a middleman who can effect enormous economies and enormous increases in efficiencies. He is a rare bird, but he should be free to flit over the whole field of defense science, its origins, and its applications.

Report on Graduate Curricula*

GEORGE R. ARTHUR†, MEMBER, IRE, AND CHARLES SÜSSKIND‡, MEMBER, IRE

During 1951–52 the Subcommittee on Graduate Curricula, under the chairmanship of George R. Arthur, Sperry Gyroscope Co., conducted a survey for the IRE Committee on Education among schools offering a graduate program in Electrical Engineering. As a result, information of considerable value was compiled on the present status and certain trends in the field of electrical, communications, and electronic engineering education. This information, tabulated and evaluated, is presented below upon the recommendation of the IRE Committee on Education and its chairman, John D. Ryder, University of Illinois
—*The Administrative Editor*

1. *Schools Reporting.*

A questionnaire was sent to 88 colleges and universities, comprising all schools approved by the Engineers' Council for Professional Development which offer graduate degrees in electrical engineering. Of these institutions, 63 returned the questionnaire. The information presented in the survey is thus substantially complete, especially as only 4 of the schools which did not return the questionnaire have a graduate E.E. enrollment of 50 or more students (Brooklyn Poly., Caltech, C.C.N.Y., and Harvard). The totals for the various columns are not shown, however, as they would not represent correct numbers.

2. *Faculty.*

The first section of the tabulation shows the size of each faculty and the portion engaged in graduate instruction (each subdivided into part-time and full-time teachers), as well as the incidence of higher degrees held by faculty members. The over-all figures indicate that little more than half of the members of faculties of E.E. departments offering graduate work are engaged in graduate instruction, and about the same proportion have doctoral degrees.

3. *Degrees Offered.*

In the 63 schools reporting, the Master's degree is the highest degree offered in 28, the Engineer's degree in 2, and the Doctor's degree in 33. Half of these institutions have been offering the Master's degree for more than 30 years. The Doctor's degree is also relatively well established: half the institutions have offered it for 15 years or more.

4. *Language Requirements.*

Only 7 schools specify that candidates for the Master's degree must show proficiency in a foreign language, and at 3 of these schools this requirement is "usually waived." The foreign-language requirements for the doctorate are even more uniform: all but two of the institutions offering this degree require two foreign languages (the exceptions require one), usually French and German. Russian or another major language is accepted as a substitute at some schools.

5. *Number of Degrees Awarded.*

This is perhaps the most reliable index of the relative size of the graduate programs at the various institutions. The "Big Three" in numbers of Doctors' degrees awarded last year were evidently Stanford (19), University of Illinois (11), and M.I.T. (10). These three schools also lead in the number of Masters' degrees awarded, though in reverse order: M.I.T. (86), Illinois (42), and Stanford (41). The comparison between 1950–51 and 1951–52 shows a considerable decrease in the over-all number of Master's degrees awarded, whereas the number of doctoral degrees remained about the same.

6. *Graduate Enrollment.*

The figures shown under this heading are significant only if they distinguish part-time from full-time students. Unfortunately, several of the schools do not differentiate between the two categories. At some universities (e.g., Maryland, Pennsylvania) the part-time students heavily outnumber the full-time students, whereas at others (e.g., California, Yale) enrollments in the two categories are of comparable size. Moreover, there is no way of distinguishing between a student carrying, say, three-quarters of the usual scholastic "load" and another registered for a single course, perhaps in night school: both would be counted as "part-time" students. The usefulness of these figures in comparing various institutions is thus limited. A comparison between the two scholastic years tabulated shows the over-all number of students enrolled for graduate work to have remained about the same.

7. *Financial Aid.*

Virtually all schools offer some form of financial aid to graduate students: assistantships, fellowships, or salaried research projects. (More than half offer all three.)

8. *Number of Publications.*

This figure represents the total number of papers and books published over a two-year period (from June 1950 to June 1952). It is to be suspected, however, that this number in some cases includes dissertations, as well as technical reports on research projects. It was not in every case possible to make an exact distinction from the answers given in the questionnaires.

9. *Sponsored Research.*

This question was intended to yield a comparison of the extent of federal-government sponsorship of research with other sponsorship (State, University, industrial, etc.). The over-all numbers show the two categories to be about equal. Unfortunately, such a comparison is not entirely satisfactory, since the size of a research program is more accurately reckoned in dollars. Furthermore, some of the large institutions returning the questionnaire deliberately omitted to answer this particular question altogether, perhaps for security reasons. It is suggested that in any future survey, this question should be worded as follows:

(a) What is the annual budget of your current *unclassified* research projects sponsored by agencies of the U. S. Government?

(b) Of projects sponsored by other public agencies (State, city, etc.)?

(c) Of projects sponsored by private sources (foundations, industry, etc.)?

(d) Of unsponsored (i.e., University or departmental) projects?

10. *Special Subjects.*

The subjects emphasized by the various institutions are identified by the code shown at the foot of the tabulation. Almost all listed "power" and "electronics" or "communications" under this heading, and these fields were therefore not shown in the tabulations. Likewise, no entry was shown for schools which reported that all fields were "equally emphasized." The intent was to point up comprehensive programs in microwave techniques, servomechanisms, and the like, rather than to register the existence of a single course in a special field. Even with this qualification, the diversity of answers was so large that the tabulation had to be restricted to 13 headings. Among the answers *not* listed were such general fields as apparatus design, circuit design, contact resistance, economics of communication services and public utilities, electric shock, electric waves, electrodynamics, electromagnetics, instrumentation, machine design, mathematical analysis, measurements, motor applications, power distribution and transmission, power-system stability and regulation, semiconductors, television, and transistors. Some of these subjects perhaps deserve to be listed, and it might be wise in the future to provide a check-list in the questionnaire, together with a clarifying statement of what is meant by "emphasized subjects."

* Decimal classification: R070. Received by the Institute June 12, 1953.
† Formerly Yale University, New Haven, Conn.; now with Sperry Gyroscope Co., Great Neck, L. I., N. Y.
‡ Stanford University, Stanford, Calif.

RESULTS OF SURVEY ON GRADUATE CURRICULA

Name of School	Faculty: Total, Part time	Faculty: Total, Full time	Faculty: Graduate, Part time	Faculty: Graduate, Full time	Faculty: Highest Degree, M	Faculty: Highest Degree, D	Faculty: Top Degree	Degrees Offered: Year 1st Given, M	Degrees Offered: Year 1st Given, D	Degrees Offered: Languages Required, M	Degrees Offered: Languages Required, D	Degrees Awarded: M, 1950-51	Degrees Awarded: M, 1951-52	Degrees Awarded: D, 1950-51	Degrees Awarded: D, 1951-52	Graduate Enrollment: Full-time, 1950-51	Graduate Enrollment: Full-time, 1951-52	Graduate Enrollment: Part-time, 1950-51	Graduate Enrollment: Part-time, 1951-52	Financial Aid	Papers Publ. 2 yrs.	Sponsored Research Projects: Gov't	Sponsored Research Projects: Other	Special Subjects
Alabama Poly. Inst.	12	—	7	—	7	—	E	'06		—		—	—			—	4	—	—	AFR	—	—	—	
Arizona, University of	—	6	3	—	4	—	M	'26		—		1	1			1	1	3	3	AF	—	—	1	e
Arkansas, University of	—	7	—	4	7	—	M	'49		—		1	1			3	—	—	3	AR	4	1	—	
California, University of	19	23	4	16	9	15	D	'05	'10	—	2	27	28	3	5	85	53	77	63	AFR		3	—	aims
Calif., University of (L.A.)	124	66	50	41	24	30	D	'45	'45	—	2	19	21	3	4	268*	236*			AFR				
Carnegie Inst. Tech.	1	15	—	12	7	8	D	'30	'40	—	1	18	17	5	7	24	23	9	10	AFR	17	10	—	
Catholic University	1	5	1	5	4	—	M	'07		1		1	2			—	—	6	12	F	2	1	1	
Columbia University	9	8	9	5	10	7	D	'10	'38	—	1	25	20	—	—	30	35	40	125	AFR	30	8	11	cinsv
Connecticut, University of	3	10	2	9	8	3	M	'40		—		3	5			1	1	63	54	AR	16	1	2	s
Cornell University	3	34	—	29	19	11	D	'21	'21	—	2	12	4	2	6	15	13	9	9	AFR	120	5	8	hims
Dartmouth College	1	2	1	2	1	2	M	'47		1		4	—			—	4	—	—	AFR	8	1	—	
Delaware, University of	—	6	—	4	6	—	M			—		2	1			—	—	10	25	AFR	1	2	1	
Florida, University of	8	6	5	1	11	2	D	'40	'50	—	2	7	2	—	—	11	9	10	7	AFR	6	5	1	nstv
Iowa State College	7	14	4	3	13	3	D	'33	'33	1	2	16	5	1	3	5	2	17	18	AFR	—	—	—	
Iowa, State University of	2	5	—	4	1	4	D			—	2	7	5	1	2	4	3	13	12	A	5	—	—	m
Illinois Inst. of Tech.	5	12	1	8	6	4	D	'37	'39	—	2	12	18	1	—	152*	120*			AFR	28	2	1	m
Illinois, University of	22	32	13	17	38	15	D			—	2	77	42	16	11	175*	105*			AFR	50	14	7	as
Johns Hopkins University	4	9	3	9	2	7	D	'16	'21	1	2	14	5	4	4	29	18	50	52	AFR	25	7	—	dh
Kansas State College	6	5	3	4	9	2	M	'10		—		4	2			4	3	9	6	AFR	6	1	4	s
Kansas, University of	2	8	1	3	4	3	D		'52	—	2	2	4	—	—	1	2	9	6	AFR	6	1	4	s
Kentucky, University of	1	10	5	—	5	2	M	'30		—		3	2			5	4	2	2	AR	2	1	1	s
Lehigh University	1	6	4	—	5	2	D		'39			—	—	—	—	9	5	—	—	AFR	6	1	—	
Maine, University of	—	0	4	—	3	1	M			—		—	1			—	—	1	1	—	1	—	2	
Maryland, University of	10	10	8	4	9	10	D	'27	'47	—	2	13	20	—	—	4	2	150	150	—	16	24*		nm
M.I.T.	5	88	2	48	15	33	D	'04	'10	—	2	107	86	11	10	88	82	151	151	AFR	141			eilms
Michigan Coll. M. & T.	—	10	—	7	6	1	M	'30		—		4	2			2	1	5	4	A	—	—	—	
Michigan, University of	4	21	2	14	18	7	D	'12	'12	—	2	31	33	4	9	119	81	92	102	AFR	11	7	17	
Minnesota, University of	10	24	—	7	16	6	D	'36		—	2									AR	7	3	1	lv
Missouri Sch. of Mines	1	9	5	4	5	1	M	'47		—		8	6			7	6	2	2	A	3		6*	s
Montana State Coll.	—	5	4	—	5	1	M	'20		—			5				4		1	F	—		4*	
Nebraska, University of	—	9	2	—	7	—	M	'10		—		1	—			1	1	2	1	A	—	—	1	
Newark Coll. of Eng.	2	9	2	7	10	2	M	'48		—		14	28			—	—	125	148	—	—	—	—	ls
New Hampshire, University of	—	6	4	—	4	—	M	'48		—		1	2			—	1	1	1	A	—	—	—	
New Mexico, University of	—	6	6	3	5	2	M	'47		—		3	2			1	—	26	33	AF	—	—	1	m
N. Carolina State Coll.	2	15	—	6	14	5	D	'34	'51	1		10	9	—	—	5	3	18	11	AFR	10	1	3	ch
Notre Dame, University of	—	8	—	4	5	1	M	'46				4	5			8	10	2	3	AFR	10	1	—	m
Ohio State University	6	16	6	7	22	7	D			—	2	28	6	4	1	9	3	46	32	AFR				t
Oklahoma A. & M.	1	11	—	7	10	2	D	'29	'51	—	2	19	6	—	—	27*	27*			AFR	28	4	—	
Penn. State College	7	14	3	3	17	1	D	'10	'25	—	2	13	5	1	—	6	8	18	29	AFR	28	4	—	hsav
Pennsylvania, University of	—	27	—	27	11	16	D	'28	'33	—	2	29	36	—	3	39	31	427	513	AFR	25			
Pittsburgh, University of	5	9	—	3	4	1	D	'27		—	2	13	13					196	203	—	—	1	—	—
Princeton University	5	10	1	8	6	5	D	'89	'46	—	2	8	8	4	5	17	13	9	11	AFR	8	3	1	ns
Purdue University	27	45	—	24	44	10	D	'05	'25	—	2	46	30	3	5	62	63	57	62	AFR	26	4	7	es
Rensselaer Poly. Inst.	2	26	1	16	8	4	D	'13	'13	1	2	19	18	—	—	16	9	30	27	AFR	17	2	—	
Rhode Island, University of	—	5	—	3	4	—	M	'50		—		—	—			1	—	10	10	A	—	2	1	
Rutgers University	2	8	4	2	5	2	M			—		18	21			1	1	85	110	AFR	6	2	2	ns
Stanford University	—	17	—	17	2	15	D	'01	'19	—	2	59	41	12	19	142*	122*			AFR	30		—	himnv
Syracuse University	1	25	1	24	18	7	D	'15	'50	—	2	4	8	1	1	6	8	150	250	F	13	4	1	n
Tennessee, University o	2	10	1	5	8	2	M	'15		—		9	6			2	—	40	50	FR	2	3	—	ps
Texas A. & M.	7	9	1	4	14	1	D	'23	'33	—	2	9	5	3	2	5	4	20	12	AFR	9	—	5	
Tulane University	—	7	—	2	—	4	M	'32		1		1	1			—	—	2	2	—	3	—	2	
Utah, University of	3	8	—	6	5	3	D	'12	'46	—	2					14	6	—	12	AFR	3	2*		
Virginia Poly. Inst.	—	9	—	4	7	—	M	'10		—		6	3			1	—	8	3	AFR	39	—	2	
Virginia, University of	5	5	—	3	5	3	M	'48		—		1	3			2	4	10	10	AFR	1	2	—	m
Washington University	2	15	—	7	4	13	D		'51	—	2	13	5	2	2	7	4	34	27	AFR	18	3	—	s
Washington St. Coll.	2	5	2	—	—		M	'16		—		1	—			1	—	4	4	F	—	—	—	
Washington, University of	1	15	—	11	10	3	M	'28		—		7	6			31	42	—	22	F	12	3	4	ms
Wayne University	7	7	2	3	9	1	M	'42		—		3	—	—	—	1	—	20	40	—	—	—	—	
West Virginia University	1	10	5	—	7	—	M	'32		—		3	2			3	—	6	6	A	—	—	2	
Wisconsin, University of	8	22	8	1	15	7	D	'20	'20	—	2	45	11	9	6	20	15	100	85	AFR	17	2	21	ms
Worcester Poly. Inst.	2	12	—	6	9	—	M	'96		—		9	4			10	3	3	3	AR	2	—	—	
Wyoming, University of	—	4	3	—	2	—	E	'47		—		1	2			2	2	1	1	AR	—	—	1	
Yale University	12	17	—	14	17	8	D	'15		—	2	27	19	3	2	27	18	18	21	AFR	32	4	4	emnst

Note—In the above, a horizontal dash stands for "none"; a blank space signifies "no answer" or "does not apply."

* Total
A —Associateships
F —Fellowships
R —Research Projects

M—Master's degree
D—Doctor's degree
E—Engineer's degree

a —antennas
c —computers
d —dielectrics
e —industrial electronics

h —high voltage & arcs
i —illumination
l —acoustics

m—microwaves
n —network analysis and synthesis
p —propagation and radiation

s —servomechanisms
t —information theory
v —vacuum-tube design and physical electronics

THE SURFACE-BARRIER TRANSISTOR*

A series of five papers
by members of the technical staff
Philco Research Division

Part I—Principles of the Surface-Barrier Transistor**

W. E. BRADLEY†, FELLOW, IRE

Summary—**This paper, consisting of five parts, describes the principle, fabrication, circuit application, and theoretical bases of a new semiconductor transducer, the surface-barrier transistor. This device, produced by precise electrochemical etching and plating techniques, operates at frequencies in excess of 60 mc while displaying the low-voltage, lower-power-consumption and low-noise properties of transistors hitherto confined to much lower frequencies.**

Part I describes the basic discovery which led to the new transistor: a new mode of hole injection produced by a broad-area metal electrode in intimate contact with a single crystal of N-type germanium. The mechanisms of hole emission, conduction, and collection are discussed, and the effect on performance of precise fabrication of germanium sections a few microns in thickness is explained.

Part II describes typical fabrication methods. A germanium blank is etched by directing to its surfaces two opposed jets of a metal salt solution, through which current passes in such polarity as to remove germanium. In addition to etching away material and disposing of the reaction products, the flowing solution cools the work. The etching is allowed to continue until the thickness of the germanium is reduced to a few microns with a tolerance of ±5 per cent of the remaining thickness. A sudden reversal of polarity then stops the etching action and immediately initiates electroplating of metal electrodes from the salt onto the freshly cleaned germanium surfaces.

Part III describes the circuit parameters of the surface-barrier transistor and the performance of typical amplifiers: a compensated video amplifier having a bandwidth of 9 mc and a gain-bandwidth product of 45 mc per stage and a neutralized bandpass rf amplifier centered at 30 mc having an insertion stage gain of 15 db. Switching times in typical switching circuits are less than 0.1 microsecond.

Part IV describes quantitatively the geometrical concepts on which the extended high-frequency performance of the device is based, namely the effect of a flat, thin section of semiconductor between emitter and collector electrodes. Part V gives the theoretical treatment of the basic internal actions of the surface-barrier transistor, hole injection, and hole-current enhancement. Experimental verification of the quantitative predictions of the theory is reported.

INTRODUCTION

IN THE course of research in the Philco Corporation laboratories a new form of transistor, the surface-barrier transistor, has been discovered. This device differs from previously discovered transistors in that it contains only one form of germanium, whereas earlier devices contained at least two forms. Alloy junction transistors, for example, are described as p-n-p or n-p-n types, while the point-contact transistor has regions of modified germanium produced by the forming process near the point contacts. The new surface-barrier transistor is an N-type transistor.

The name "Surface-Barrier Transistor" is derived from the fact that the interfaces of the transistor which perform the functions of emission and collection of the useful current are located *at the surface* of a uniform crystal-base electrode. The development of an active interface located at the crystal surface results in a new mode of operation upon the charge carriers of the crystal permitting the use of metal electrodes of relatively large area.

The fact that the electrodes are applied to the surface of the crystal after the crystal has been shaped permits accurate control of the geometry of the transistor to a degree unheard of in prior art. Accurately controlled fabrication of N-type germanium in sections a few microns in thickness is readily achieved, for example, by the electrochemical techniques described by Tiley and Williams.[1]

The practical result of this new principle and the associated techniques is a transistor of unprecedented performance characteristics. Efficient operation on a power supply of three volts or less at frequencies above 60 megacycles has been achieved and substantially higher frequency operation is anticipated with further refinement of the fabrication method. Band-pass amplification centered at a frequency of 30 megacycles has been demonstrated and low-pass amplification from zero to 9 megacycles has been achieved. In brief, the surface-barrier transistor combines low-voltage, low-power-consumption, low-noise-figure operation at frequencies higher by more than an order of magnitude than can be attained with available alloy-junction transistors.

The principles and techniques embodied in the surface-barrier transistor are applicable not only to the particular type described herein but also to other forms, as those familiar with the art will readily appreciate from the detailed description of the electrochemical technique in the associated paper.[1]

THE SURFACE BARRIER OF N-TYPE GERMANIUM

The useful current of the surface-barrier transistor is a current of holes moving from the emitter to the collector. The free electrons which are normally present in

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† Philco Corp., Research Div., Philadelphia, Pa.

[1] PROC. I.R.E., pp. 1706–1708; this issue.

large quantity in N-type germanium would short-circuit the device if it were not for the action of the surface barrier which tends to push the free electrons back from the surface.

The surface barrier includes the surface and a layer of germanium just beneath the surface of the crystal which is about one ten-thousandth of an inch thick and contains almost no free charge carriers, either electrons or holes. This layer (shown schematically in Fig. 1) is practically an insulator, but contains a strong electric field, like a charged condenser, in such a direction as to move a free electron from the surface toward the interior.

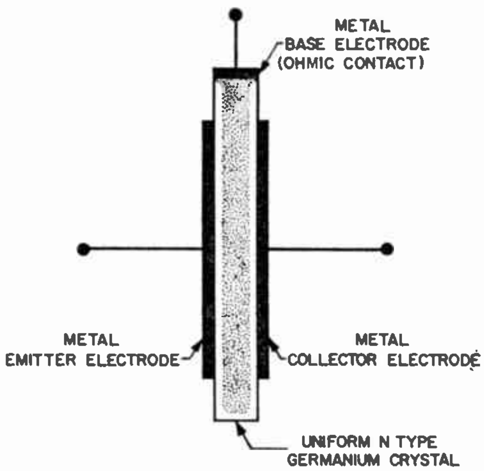


Fig. 1—Schematic cross section of surface-barrier transistor.

The formation of the surface barrier is related to the fact that electron energy levels, or orbits, may exist on the surface of a crystal which are quite different from those in the interior of the crystal. Inside the crystal the orderly array of atoms of a single element gives rise to an orderly arrangement of bands of allowed electron energy separated by forbidden bands.

Many excellent expositions of bulk properties of semiconductors exist in the literature and no repetition will be attempted here. Not so much attention has been paid so far to the surface of the crystal. Here the left-over bonds of the germanium atom, together with any atoms of other substances on the surface, may form a sort of two-dimensional solid with properties entirely different from the interior. Thus insulating crystals may exhibit high surface conductivity due to a layer only one or two atoms thick which can pass electrons from atom to atom along the surface freely. It is possible that no orderly structure of energy bands exists on such a surface, since it may be composed of many kinds of atoms, or ions, in many orientations. It is fairly safe to assume that the energy levels of such a layer form a near continuum, with no forbidden bands at all.

Inside a crystal of N-type germanium the free electrons move in a high-energy, nearly empty band. Lower in energy is a forbidden band and below that the so-called valence band which is filled completely. The free electrons tend to descend in energy to fill any available vacancy and hence are attracted to the surface. So many electrons may move to the surface in this way that it acquires a strong negative charge repelling free electrons toward the interior and causing a nearly insulating region containing a strong electric field, just beneath the surface.

Electron Current Through a Surface Barrier

A metal electrode in intimate contact with such a germanium crystal makes firm electrical connection to the surface layer but communicates with the main body of the crystal only through the surface barrier. Making the metal negative tends to repel the free electrons even more, thickening the insulating layer so that little current flow takes place. Making the metal positive attracts free electrons, making the insulating layer thinner, permitting current to flow.

Hole Current Through a Surface Barrier

While the above mechanism explains rectification at a surface contact, it is not sufficient to explain the surface-barrier transistor because it ignores the current of holes which is the only useful current component. The existence of a set of energy levels at the surface which are intermediate between the conduction band and the valence band implies that thermal agitation will frequently excite valence electrons of the crystal into the surface levels. It will be recalled that even in the interior of the crystal electrons are occasionally thermally excited from the valence band to the conduction band. Remembering that the probability of such a transition varies exponentially with the energy difference, changing by about a factor of e for each 1/40 of a volt, and that the band spacing of germanium totals about $\frac{3}{4}$ electron volts, it is clear that if intermediate levels are available, electrons from the valence band will be excited into them fairly frequently so there will be, under equilibrium conditions, a population of holes just under the germanium surface.

Some metal contacts produce a denser hole population under the surface of the germanium than others. Differences between metals in their propensity to emit holes into N-type germanium have been found, in apparent contradiction to results obtained elsewhere, when the metals are deposited electrolytically upon a freshly etched surface of germanium. The mechanism by which the potential of the surface layer adjusts itself with respect to the metal is difficult to treat theoretically in quantitative fashion. Upon the adjustment of the metal potential with respect to that of the germanium depends the height of the surface barrier and the density of holes under the surface.

The effect of the surface barrier is to force these holes to remain near the surface just as it forces free electrons to remain in the interior. When a metal contact to the crystal is made positive it repels these holes through the barrier just as it attracts the free electrons. The result is that the forward current of the rectifier is made up of two currents in parallel, the hole current and the electron current. For transistor purposes it is desirable to reduce the electron current as much as possible since only the hole current is received at the collector.

It is clear that a back-biased metal contact can serve as a collector of holes since the surface-barrier field augmented by the back bias will infallibly draw holes coming within its reach out to the surface.

Enhancement of Ratio of Hole Current to Electron Current

Some precautions are necessary for a metal contact to serve as emitter of holes with the electron current reduced to a low value.

In the first place, the metal should have the property that when applied to the surface it produces a satisfactorily high density of holes in the adjoining germanium. Among the metals found to be satisfactory for this purpose are indium, zinc, cadmium, tin, and copper.

Inside the body of the germanium crystal the large number of charge carriers present makes the electric field very small. The absence of any substantial electric field causes the holes to move to the collector *principally by thermal diffusion.* Such a diffusion current flows only when a gradient of hole density exists. Such a gradient implies a larger density of holes in the bulk material near the emitter barrier than near the collector barrier. Unfortunately, the effect of high density of holes near the emitter barrier, coupled with the random nature of the diffusion process, tends to cause a large proportion of holes to diffuse back to the emitter reducing the net hole current. Worse yet, the increased hole population attracts an equal number of electrons by its space charge, increasing the electron population near the surface barrier and, hence, the undesired electron current. The distribution of holes and electrons during operation is shown in Fig. 2.

The most effective means of enhancing the hole current for large-area contacts is to make the hole-density gradient through the base as steep as possible. A high value of gradient increases the current directly without increasing the hole density and, therefore, without increasing the electron current. By bringing the collector close to the emitter the gradient can be proportionately increased since the hole density is reduced by the action of the collector.

Application to Surface-Barrier Transistor

In the surface-barrier transistor the spacing between the metal electrodes has been successfully reduced to a few microns with good control of the process. This excellent control is possible because the electrodes are applied to the *surface*, so that it is possible to shape the germanium crystal itself to the required geometry and apply the electrodes afterward.

Unfortunately, most shaping processes strain the surface of the structure being shaped and, as can be seen from the discussion above, it is important for a surface-barrier transistor to have undisturbed germanium all of the way out to the surface. Chemically or physically inhomogenous germanium crystals or uneven metal contacts tend to produce inefficient and variable operation because of nonuniform structure at the resulting surface barrier.

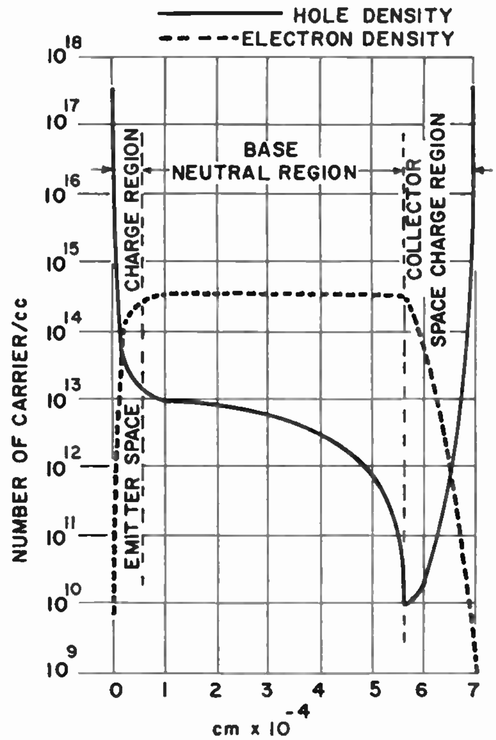


Fig. 2—Variation of densities of hole and electrons with distance in the space between emitter and collector electrodes.

Electrochemical Fabrication

Accurate shaping of the crystal, together with intimate electrode contact without disturbance of more than one atomic layer of crystal, has been achieved by a process of "electrolytic machining." Tiny jets of metal salt solution with current passing through them dissolve germanium from the crystal wafer until cavities of the right size and shape have been excavated. By a mere reversal in polarity, and without any interruption, the same jets are made to electroplate the electrodes directly upon the freshly etched surface of germanium. Many salt solutions are suitable for the electrolytic processes. A cross section of the resulting structure is shown in Fig. 3(a).

Experimental Results with Electrochemically-Deposited Surface Electrodes

The uniformity of the surface barrier produced by the electrolytic assembly process is proved by the shape of the current versus voltage curves of an electrode with respect to the base. The theory of metal-to-semiconductor contacts predicts that the current should consist of a constant (the saturation current), plus a term which increases exponentially with forward bias.[2] The important thing is that this exponent should be numerically equal to about forty times the voltage. Exponents as large as this have not been found with any other type of metal-to-germanium contact so far as we have been able to determine. Exponents of forty times the voltage are usually obtained with high-quality alloyed or pulled junctions, although with these accuracy of dimensional control is much more difficult. Exponents of this value are normally obtained with metal electrodes applied by the electrochemical process, showing that the increased dimensional accuracy of the surface-barrier transistor has been achieved without sacrifice of essential barrier uniformity.

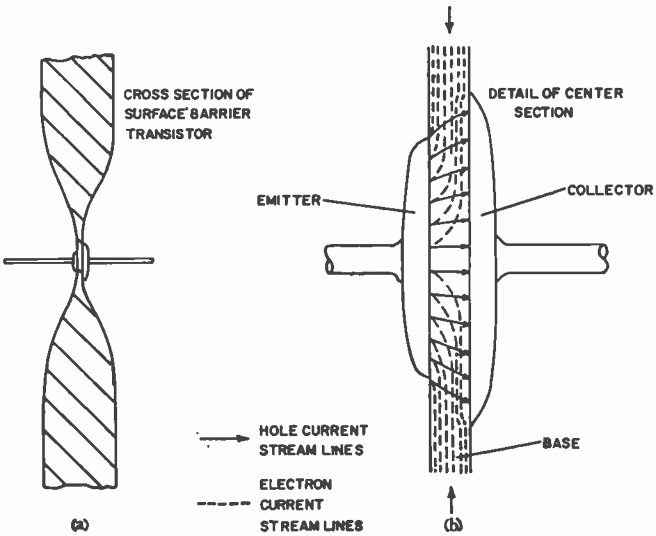


Fig. 3—(a) Cross section of surface-barrier transistor. (b)—Detail of center section.

Unlike the point-contact transistor, the hole current of the surface-barrier transistor is protected from exposure to uncovered germanium surface. The action of such an exposed surface as a collector or as a conductor of holes is subject to variation with time because of variations of the chemical composition of the surface layer of adsorbed atoms on the crystal. The steam lines of flow of hole current in the surface-barrier transistor (Fig. 3(b)) are all nearly equal in length and extend directly from emitter to collector without any appreciable diffusion to the exposed crystal surface.

The extreme uniformity of the barrier gives another useful result. The high exponent value implies that, like alloy- or pulled-junction transistors, the device will operate on very low voltages. The characteristic curves of the surface-barrier transistor in Fig. 4 show that the collector impedance becomes high for potentials above one-quarter of a volt.

Not only does the close spacing of emitter and collector cause the emitter current to consist almost entirely of holes, but it permits operation with low voltages at frequencies, which it has proved impractical to obtain with other forms of transistors. Operation on a 3-volt power supply at 30 megacycles with a power gain of 18 db has readily been obtained.

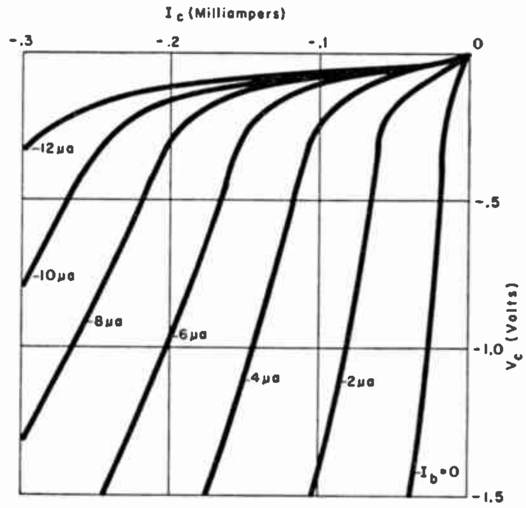


Fig. 4—Grounded-emitter characteristics of a typical surface-barrier transistor.

The most important characteristics of a group of ten surface-barrier transistors are tabulated in Table I. The column labeled $f_{c\alpha}$ is the frequency at which the hole current falls to seven-tenths of its low-frequency value with constant signal input.

The surface-barrier transistor is at present a low-power device. This is not inherent but reflects the fact that our research program was guided partly by our dissatisfaction with the high-frequency performance and uniformity of existing low-power transistors. The power output of the transistors in Table I is of the order of milliwatts.

TABLE I

Parameters of Surface-Barrier Transistors Measured at $V_c = -3$ Volts $I_c = -0.5$ ma

Unit	$f_{c\alpha}$ (mc)	α_0	r_e (ohms)	r_c (kilohms)	r_b (ohms)	r_b' (ohms)	C_c ($\mu\mu$f)
148	40	0.912	21	200	800	320	2.0
149	41	0.925	47	280	730	180	1.5
150	36	0.913	18	155	780	160	2.1
152	47	0.910	23	210	610	185	2.7
200	37	0.912	31	160	560	200	2.2
214	40	0.961	33	265	1120	190	2.5
217	49	0.905	11	160	650	130	2.2
219	47	0.962	13	330	1500	235	1.7
226	47	0.925	59	220	970	220	1.3
227	44	0.922	17	210	920	190	1.0

Future Prospects

It is clear that the discovery that unformed surface electrodes of substantial area when properly applied are suitable for transistor use, together with the fact that semiconductors can be accurately shaped by electrochemical techniques, opens up a promising new area of research and development in the already vigorous field of applied semiconductor physics.

[2] For example, see H. C. Torrey and C. A. Whitmer, "Crystal Rectifiers," p. 77, Section 4.3, McGraw-Hill Book Co., Inc.; 1948.

Using the electrochemical method it is easy to assemble multielectrode structures on a single crystal blank, to apply a number of metals in succession for various purposes, and to locate electrodes with microscopic accuracy. Such a considerable extension of our present ability to control the important parameters of transistors and related devices appears certain to lead to a new family of useful products of which the surface-barrier transistor is the first member.

Acknowledgment

The discovery and development of the surface-barrier transistor have resulted from the co-ordinated efforts of many individuals of the Philco Research Division, all of whom unfortunately cannot be mentioned by name. The authors of the companion papers following merit special mention for work which is reflected, in part, in their contributions to this issue of the Proceedings. E. H. Borneman, A. D. Rittmann, John Roschen, T. V. Sikina, and R. J. Turner have contributed substantially to the understanding of the device, its fabrication and measurement. In addition, W. H. Forster, co-ordinator of the transistor program, and C. V. Bocciarelli, in charge of the applied physics section, have made important contributions to the technical and administrative phases of the work. Finally, the author wishes to acknowledge the creative support of C. L. Stec of the Electronics Design Division, Bureau of Ships, Navy Department.

Part II—Electrochemical Techniques for Fabrication of Surface-Barrier Transistors*

J. W. TILEY†, member, ire, and R. A. WILLIAMS†

Introduction

Mechanical precision is a basic requirement in the fabrication of all types of transistors. In many cases the limitations on performance, particularly with respect to gain and maximum frequency of operation, are a function of the ability of the fabrication process to hold close mechanical tolerances. Electrochemical techniques have succeeded in producing, reproducibly, minority-carrier transistors with dimensional tolerances of less than one micron. As reported in companion papers,[1] experimental surface-barrier transistors optimized for high-frequency response uniformly have alpha cutoffs between 35 and 50 mc, more than four octaves higher than commercially available alloyed-junction or grown-junction transistors. It is the purpose of this paper to describe the basic electrochemical processes by which germanium-indium surface-barrier transistors are fabricated and to indicate the capabilities of the processes with respect to holding mechanical tolerances on the finished transistor.

Fabrication Processes

The germanium-base structure for the surface-barrier transistor is cut from single-crystal N-type germanium of appropriate resistivity and adequately high minority-carrier lifetime. The wafers are then lapped to the desired thickness. The rectangular germanium blanks for the present experimental surface-barrier transistors are 0.050×0.100 inch lapped to a thickness of 0.006 inch. Abrasive cutting of the crystal causes flaws and lattice disorder near the ground surface. This requires the subsequent removal of the disturbed layer by a more gentle means. Carefully controlled chemical etching is used for the preparation of an undisturbed surface and, in the process, reduces the thickness of the lapped blank to 0.003 inch. A nickel contact is then soldered to one end of the blank.

The ultimate thickness desired for the active region of the final base electrode is on the order of a few microns. Such a thin section of crystal is fragile unless well supported and, for this reason, as well as to maintain low base resistance, only the active region is reduced to this thickness. What is required at this stage is an accurately controlled process which can reduce the base electrode thickness without disturbance of the crystal surface.

Jet Electrolytic Etching

A system of electrolytic etching has been developed using two small jets of a salt solution. A pair of glass nozzles, approximately 0.005 inch in diameter, are mounted on a common axis so as to direct jets of liquid toward each other. The germanium blank is placed in the mid-plane between the two nozzles so that the jets strike opposite sides of the blank simultaneously as shown in Fig. 1. The complete electrochemical system is illustrated in Fig. 2. The germanium wafer is connected as the anode with electrodes in the glass nozzles as the cathodes.

The use of jets of electrolyte eliminates uneven etching caused by gas bubbles, reaction products, and so forth, and, in addition, produces directly the desired shape of excavation without the necessity of masking any portion of the surface. Etching action is principally confined to the region immediately under the jet since the electrolyte spreads out in a thin sheet across the

* Decimal classification: R282.12. Original manuscript received by the Institute, Oct. 14, 1953.
† Philco Corp., Research Div., Philadelphia, Pa.
[1] Proc. I.R.E., pp. 1702, 1709, 1715; this issue.

surface of the wafer. If the resistivity of the solution is of the same order of magnitude as that of the germanium, the current density must fall off rapidly with radial distance from the jet axis.

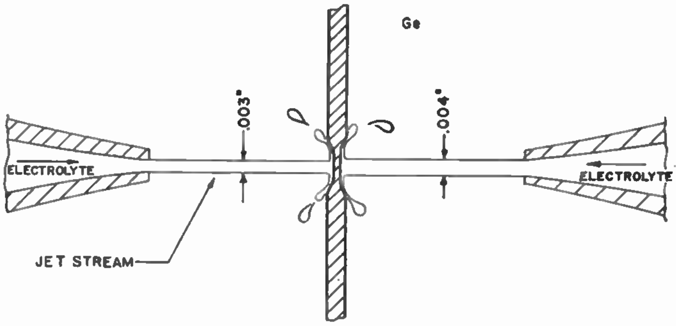


Fig. 1—Axially-aligned glass nozzles direct jets of electrolyte against the germanium wafer.

An interesting aspect of the process, requiring careful attention but leading to a valuable means of control, results from the fact that the solution during etching is biased *in the back direction* with respect to the germanium. This would prevent current from passing between the germanium and the solution except for the effects of saturation current augmented by the effect of light which produces pairs of carriers in the barrier region. Control of the light level is therefore important during the process.

A most useful aspect of this back-biased barrier appears as the excavations produced by the two jets approach each other. The surface barrier extends into the germanium on the order of 0.0001 inch beneath the surface, and this region is many orders of magnitude higher in resistivity than the interior due to the relative absence of free charge carriers. As the two surface barriers approach each other, the current density is reduced to a low value controlled to a considerable extent by the ambient light level. As a result, the etching action slows down and a flat bottom tends to form in each excavation with a thin window separation. This window etches more and more slowly so that its thickness can be controlled under appropriate conditions of light level, solution concentration, and power-supply voltage.

Kansas[2] shows that a base having a uniform thickness over the active region should have much better high-frequency performance than one having the usual bi-concave form. It is therefore desirable to use the central region of the excavation, where the thickness is most uniform, for the active portion of the base.

Jet Electroplating

Many metallic salts are suitable for electrolytic etching of germanium using the technique described above. The salt actually used is chosen on the basis of suitability for electroplating the appropriate metal.

A mere reversal of polarity without readjustment of anything except the total current is sufficient to convert the action of electrolytic etching into electroplating, the metal ions of the salt solution being deposited in the form of dots in the bottom of the excavations produced by the etching. Several metals have been found to meet the requirements of surface-barrier transistor electrodes. The developmental samples discussed by Schwarz and Walsh were prepared using indium.[3] For this metal the sulphate or chloride in a 0.1 normal solution of low pH have been found to be suitable. A pressure on the order of 15 lbs. per sq. in. is used to produce a high-velocity jet stream. The pattern flow of electrolyte is shown schematically in Fig. 1.

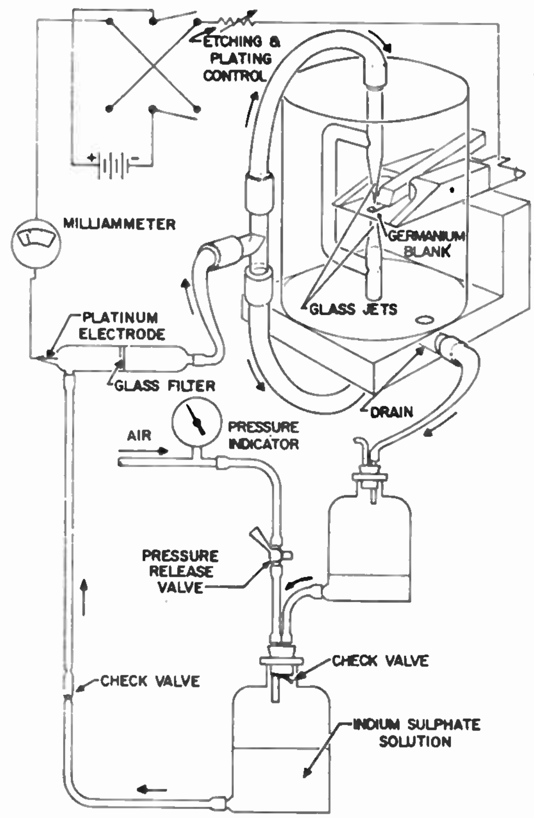


Fig. 2—Schematic diagram of electrochemical processing system.

Etch-Pit Geometry

The current density for the etching process falls off rapidly with radial distance outside the edge of the well-defined jet. More accurately defined pits result from a high-resistivity electrolyte, but the geometric requirement favors the larger, flatter pit obtained with the lower resistivity solution.

A typical etching current for a 0.010 inch pit is 1.5 ma and requires a voltage of 200–300 volts because of the high resistivity of the jets. This current corresponds to approximately 20 amperes per sq. in.—an extremely high etching current made possible by the cooling action inherent in the rapidly flowing electrolyte.

Typical surface-barrier transistors are designed to have a barrier spacing of 0.0002 inch. Starting with a

[2] Proc. I.R.E., pp. 1712–1714; this issue.

[3] Proc. I.R.E., pp. 1715–1720; this issue.

0.003 inch wafer, etching time ranges from 90 to 120 seconds. A pilot hole is etched to determine the time required for "break through." The time for etching the pits to the desired depth is then reduced accordingly. The etched wafer of Fig. 3 has been sectioned to show typical geometry, which, in actual practice, can be held to a tolerance of ±5 per cent of the remaining thickness of germanium.

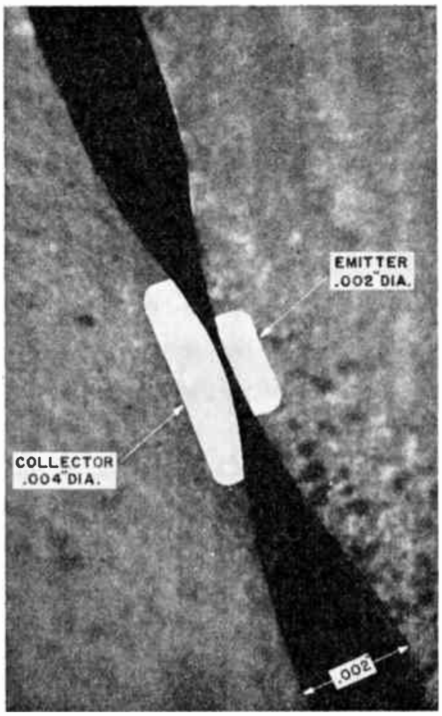


Fig. 3—Photomicrograph of etched germanium wafer. Dimensions and typical emitter and collector electrodes are shown in white.

It is important that the indium electrodes be deposited on a clean, undisturbed surface of the germanium wafer. For this reason the plating phase is caused to follow the etching phase by an instantaneous reversal of the polarities. Optimum transistor geometry results with electrodes relatively small compared with the etch-pit diameters. Typical units, with 0.015 inch pits, use 0.003 inch emitters and 0.006 inch collectors.

The "throwing power" of the plating solution, and, hence, the diameter of the indium electrodes, can be varied by adjusting the pH. Experience has shown that good results are obtained by adding sulphuric acid to lower the pH to the range of 1.2 to 3.5. With constant electrolyte resistivity, the area of plating can be controlled by modifying the pH.

During the plating phase, the barrier formed by the germanium and the electrolyte is biased in the forward direction; hence, light has little effect. The optimum plating current is, in general, lower than for the etching phase. The currents during the two phases have independent adjustments ganged with the polarity-reversing switch.

Electroplated indium has a strong tendency to form dendritic growths. This is, in part, a function of the plating solution. In practice it is found that 0.0005 inch is a satisfactory thickness for both emitter and collector electrodes.

Surface Treatment and Packaging

Experience has shown that a surface clean-up etch is desirable to remove contaminants which would otherwise produce low output impedance and feedback around the barrier where it is exposed at the periphery of the indium electrodes. An etch composed of HF, HNO_3 and H_2O is satisfactory for reducing leakage currents and for maximizing the dynamic back resistance of the collector barrier.

The processed germanium wafer, etched and plated, is mounted by its base tab on a glass stem which forms the base of the hermetically-sealed metal envelope. Leads are connected between the base pins and the emitter and collector as shown in Fig. 4. The transistor is then encapsulated in polystyrene and hermetically sealed into the container. It is advisable to use sealed construction even for experimental units.

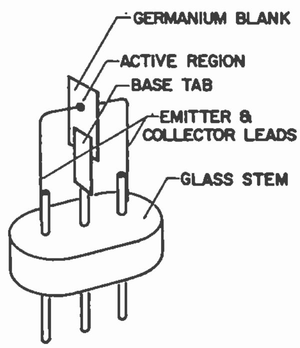


Fig. 4—Surface-barrier transistor mounted on experimental glass stem.

Conclusions

Experience has already shown that these electrochemical processes are easily capable of fabricating germanium transistors to tolerances measured in millionths of an inch. It seems safe to conclude that these techniques will find wide application in the fabrication of semiconductor devices such as the surface-barrier transistor and others still to come.

Acknowledgment

The authors wish to thank Mrs. Elizabeth Zimmerman who assisted in the fabrication of the earliest experimental units.

Part III—Circuit Applications of Surface-Barrier Transistors*

J. B. ANGELL†, ASSOCIATE, IRE, AND F. P. KEIPER†, JR., ASSOCIATE, IRE

Introduction

THE low power consumption of transistors makes possible their use in a variety of applications where vacuum tubes have been limited because of their high power requirements. The surface-barrier transistor, described in the companion papers, extends the very low power features of certain transistor types to a new class of applications.

Point-contact transistors have been used as high-frequency oscillators and amplifiers at frequencies up to hundreds of megacycles.[1,2] Such units typically require collector-supply power of 25 mw or more from a power supply of 10 volts when operating at high frequency, and may have high base resistance, which adversely affects their stability and limits their usefulness as amplifiers. Junction transistors of the tetrode variety have been used as amplifiers above 50 mc and as oscillators at frequencies well above 100 mc.[3] With these units, the total power-supply requirement runs on the order of 50 mw, with supply voltages in excess of 15 volts, for this frequency range of operation.

Performance figures for the surface-barrier transistor circuits described in this paper have been obtained with a total power-supply drain of slightly over 2-mw per transistor and with a maximum collector-supply voltage of 3 volts. The surface-barrier transistor operates at the low power-supply levels of the junction-triode transistors, but is useful at appreciably higher frequencies.

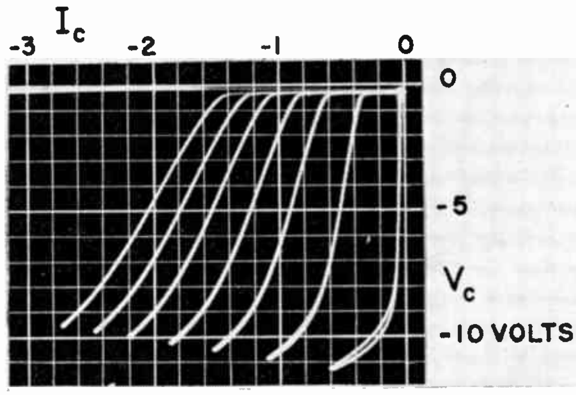
Typical characteristics for a surface-barrier transistor with $V_c = 3$ volts and $I_e = 0.5$ ma are given below:[4]

$r_b = 850$ ohms (low-frequency apparent base resistance)
$r_{b'} = 200$ ohms (high-frequency apparent base resistance)
$C_c = 1.9\ \mu\mu f$
$\alpha = 0.93$
$f_{ca} = 43$ mc (measured in neutralized circuit)
$r_e = 30$ ohms
$r_c = 200$ kilohms.

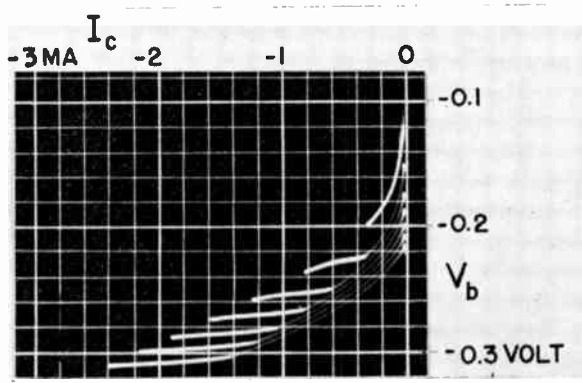
Fig. 1, collector characteristics for such a transistor.

Results obtained from the application of surface-barrier transistors to typical circuits will now be described, including derivations of useful figures of merit for these surface-barrier transistor applications.

(a)



(b)



($\Delta I_b = -20\mu$ amp per step)

Fig. 1—Grounded-emitter collector and feedback characteristics of surface-barrier transistors. The slope of the collector characteristics (a) is $r_e(1-\alpha)$. The slope of the active (bright) portion of the feedback curves (b) is r_e, and the vertical spacing is the open-circuit input impedance times the base current increment, $(r_e + r_b)\Delta I_b$.

Wide-Band Low-Pass Amplifiers

Wide-band amplifiers which may be required to pass all frequencies from the low audio range up to many megacycles must, of necessity, employ direct or capacitive coupling, since transformers covering such a wide relative range of frequencies are not available. The most efficient directly-cascaded, low-pass transistor amplifier uses a grounded-emitter connection for all stages. The direct coupling implies that the input impedance of any stage in a cascade is equal to its load impedance, the latter being the input impedance of the following stage. This condition is used as a basis for establishing a figure of merit.

* Decimal classification: R282.12. Original manuscript received by the Institute, Oct. 14, 1953.
† Philco Corp., Research Div., Philadelphia, Pa.
[1] B. N. Slade, "The control of frequency response and stability of point-contact transistors," PROC. I.R.E., vol. 40, pp. 1382–1384; Nov., 1952.
[2] G. M. Rose and B. N. Slade, "Transistors operate at 300 mc," *Electronics*, vol. 25, p. 116; Nov., 1952.
[3] R. L. Wallace, Jr., L. G. Schimpf, and E. Dickten, "A junction transistor tetrode for high-frequency use," PROC. I.R.E., vol. 40, pp. 1395–1400; Nov., 1952.
[4] For definitions see R. F. Schwartz and J. F. Walsh, "List of Symbols," p. 1720; this issue.

For equal input and load impedances it can be shown that the voltage gain of a grounded-emitter stage, in terms of the open-circuit impedance parameters,[5] is given by

$$G_v = \frac{v_2}{v_1} = \frac{i_2}{i_1} \approx \frac{-Z_{21}}{Z_{11} + Z_{22}}, \tag{1}$$

where the approximation, for the parameters of the surface-barrier transistor, is good within 1 per cent at all frequencies. Upon substitution of the appropriate impedance values, the voltage gain is found to be

$$G_v = \frac{\alpha}{1 - \alpha + \frac{r_b}{Z_c}}, \tag{2}$$

where Z_c is the complex collector impedance resulting from r_c and C_c in parallel. The low-frequency voltage gain is

$$G_v = \frac{\alpha}{1 - \alpha + \frac{r_b}{r_c}}. \tag{3}$$

The bandwidth of a low-pass amplifier may be limited by either collector capacitance or by the α cutoff frequency.[3] For the collector-capacitance limitation the bandwidth in cycles per second is given by

$$BW = \frac{1}{2\pi C_c r_b}\left(1 - \alpha + \frac{r_b}{r_c}\right). \tag{4}$$

This expression, combined with (3), gives a capacitance-limited gain-bandwidth product of

$$G_v \times BW = \frac{\alpha}{2\pi C_c r_b}. \tag{5}$$

For the surface-barrier transistors this gain-bandwidth product is typically 100 mc, which is large compared with the limitation due to α cutoff.

For an α cutoff bandwidth limitation, the low-frequency gain is still given by (3). If it is assumed that alpha falls off according to

$$\alpha = \frac{\alpha_0}{1 + j\frac{f}{f_{c\alpha}}}, \tag{6}$$

then the bandwidth of an iterated stage is

$$f = f_{c\alpha} \times \frac{1 - \alpha + \frac{r_b}{r_c}}{1 + \frac{r_b}{r_c}}. \tag{7}$$

[5] The application of open-circuit impedance parameters to transistor circuits is given by R. L. Wallace, Jr. and W. J. Pietenpol, "Some circuit properties and applications of *n-p-n* transistors," Proc. I.R.E., vol. 39, pp. 753–767; July, 1951.

Therefore, for this case the voltage gain times bandwidth is

$$G_v \times BW = \frac{\alpha_0}{1 + \frac{r_b}{r_c}} \times f_{c\alpha} \approx f_{c\alpha}. \tag{8}$$

The above figures of merit give the voltage gain-bandwidth product for a directly connected, grounded-emitter cascade. These figures will be appreciably lower than the power-gain bandwidth product for optimum load impedance that is frequently quoted for transistor performance.

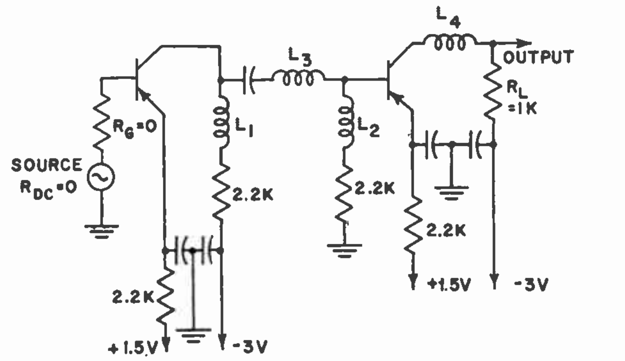


Fig. 2—Schematic of 9-mc bandwidth, 28-db gain video amplifier using surface-barrier transistors.

A typical video amplifier with surface-barrier transistors is shown schematically in Fig. 2. The shunt chokes, L_1 and L_2, employed in this circuit are for the purpose of isolating the bias-supply resistors at the higher frequencies, thus increasing the net stage gain at higher frequencies. Peaking circuits are formed by the series coils, L_3 and L_4, resonating with the transistor output capacitances. Using transistors having α cutoff frequencies of approximately 45 mc, a gain of 28 db and a bandwidth of 3.2 mc was obtained for the 2-stage amplifier without the chokes. The addition of the chokes resulted in increasing the bandwidth to 6.5 mc without affecting the gain, while chokes plus peaking coils gave a 9.0-mc bandwidth. With the chokes and the peaking coils, the voltage gain-bandwidth product per stage was 45 mc. Fig. 3 shows the frequency response and transient response for the various amplifier configurations.

Surface-barrier transistors have also been used in typical switching-circuit applications, such as 2-transistor multivibrators and flip-flops. Since such circuits are essentially overdriven low-pass amplifiers, the same transistors are suitable in both applications. With surface-barrier units switching times of less than 0.10 μsec have been obtained with a 3-volt collector supply.

Bandpass Amplifiers

When using transistors as high-frequency bandpass amplifiers, care must be taken to avoid regeneration due to inherent feedback within the transistor. One method

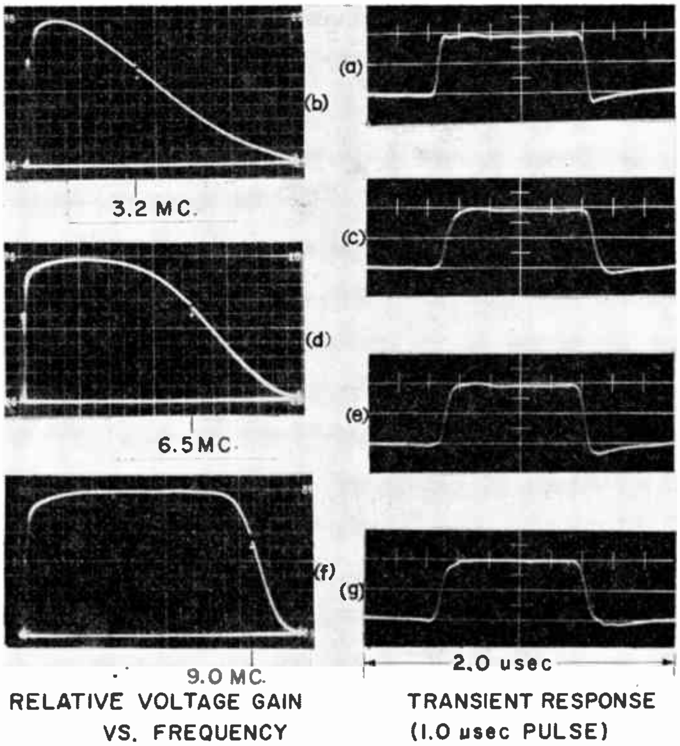


Fig. 3—Frequency and transient response of video amplifier. (a) Input pulse, (b), (c) amplifier with neither chokes nor peaking coils, (d), (e) amplifier with chokes only, (f), (g) amplifier with both chokes and peaking coils.

for avoiding this regeneration is the use of a neutralizing circuit. A suitable means for neutralizing a grounded-base stage with a transistor having negligibly high collector resistance is shown in Fig. 4. The components r_N and C_N, together with the internal base resistance and collector capacitance of the transistor, form a bridge for isolating the input from the output, as the equivalent circuit shown in Fig. 4 indicates.[6]

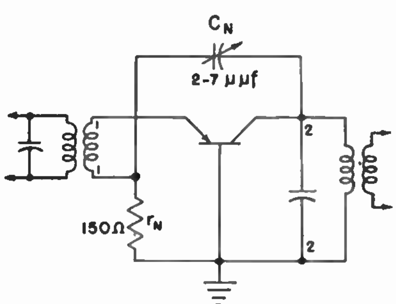


Fig. 4—Neutralized tuned 30-mc amplifier. The 3-volt collector supply and the 0.5-ma emitter supply are omitted for clarity.

The maximum power gain available from a neutralized stage with a transistor having negligibly high collector resistance may be evaluated as follows. The open-circuit impedances for the neutralized stage, shown in Fig. 5, are

$$\left.\begin{aligned} Z_{11} &= r_e + r_b''(1-\alpha) + \frac{(1+A-\alpha)r_b'}{1+jr_b'/X_c} \\ Z_{12} &= 0 \\ Z_{21} &= -j\alpha X_c \times \frac{A}{1+A} \\ Z_{22} &= (r_b' - jX_c) \times \frac{A}{1+A} \end{aligned}\right\} . \qquad (9)$$

At resonance, the real part of the load impedance for matched conditions should be $Ar_b'/1+A$, since $Z_{out} = Z_{22}$. If "A" is approximately unity, the most typical case, and $1-\alpha$ is very much less than unity, the power gain is

$$G_p = \frac{R_L}{R_{in}} \times \left|\frac{i_2}{i_1}\right|^2 = \frac{R_L}{R_{in}} \times \left|\frac{-Z_{21}}{Z_{22}+Z_L}\right|^2$$
$$\approx \frac{\alpha^2}{8} \times \left(\frac{X_c}{r_b'}\right)^2 = \frac{\alpha^2}{8(2\pi f r_b' C_c)^2}, \qquad (10)$$

where the approximation is good to within 1 or 2 db for most surface-barrier transistors. It should be noted that the product of base resistance (measured at the frequency of operation) and collector capacitance is a fundamental parameter controlling the gain. The low collector capacitance of surface-barrier transistors makes them suitable for this application.

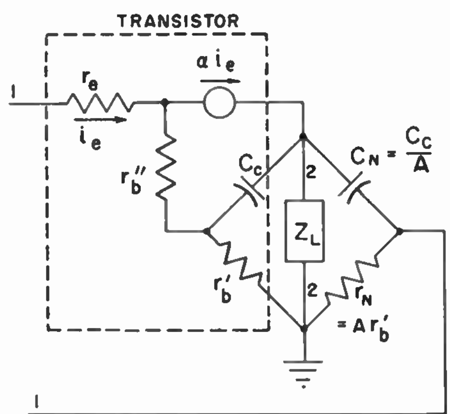


Fig. 5—Equivalent circuit of neutralized amplifier.

Using a barrier transistor having a α cutoff frequency of close to 50 mc in the circuit of Fig. 4, an over-all, nonregenerative, circuit insertion gain of 13 db at 30 mc, including coil losses of 5 db, was obtained.

Since any bandpass amplifier with a gain greater than unity can be made into an oscillator, a good high-frequency amplifier will also form a stable high-frequency oscillator. Using barrier transistors, oscillators operating as high as 70 mc have been constructed using a 3-volt power supply. See Fig. 6, page 1712, for oscillator circuit with such performance. The external feedback element, C_f, is used to compensate for phase shift within the transistor.

[6] The high-frequency equivalent circuit for the transistor has been suggested by J. M. Early, "Effects of space-charge layer widening in junction transistors," PROC. I.R.E., vol. 40, pp. 1401–1406; Nov., 1952.

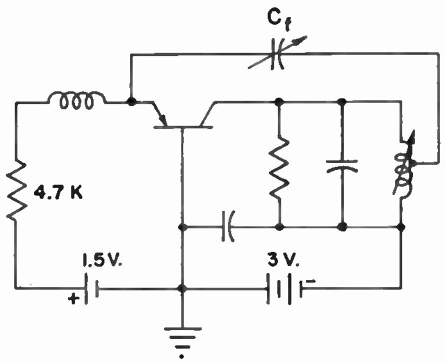


Fig. 6—Surface-barrier transistor 70-mc oscillator.

Conclusion

Typical circuits requiring high-frequency performance have been constructed using surface-barrier transistors. These circuits have all been operated with 3-volt collector supplies. Video amplifiers with 5-mc bandwidths and tuned amplifiers at 30 mc have shown stage gains of 15 db or more. Trigger circuits have had switching times of 0.10 μsec or less. Oscillators have operated reliably at 70 mc. The surface-barrier transistor has shown itself capable of extending the very low-power advantages of the junction-triode transistor up into the vhf frequency range.

Part IV—On the High-Frequency Performance of Transistors*

ROBERT KANSAS†, ASSOCIATE, IRE

Theory

THE USUAL ANALYSES of junction transistors assume a one-dimensional structure for the purpose of simplifying the calculations. Typical of these are the analyses of Shockley, Sparks, and Teal,[1] and Steele.[2] Both lead to the result that the alpha cutoff frequency of the transistor is given by[3]

$$f_{c\alpha} = \frac{D}{\pi a^2}. \tag{1}$$

The logical method of arriving at this result is given most simply in Steele's article.[2] Briefly, the method consists of the following steps:

1. The emitter current, I_e, and the collector current I_c, are calculated.
2. The short-circuit current gain, α, is calculated.

$$\alpha = -\left.\frac{\partial I_c}{\partial I_e}\right|_{V_c}.$$

3. The frequency at which the magnitude of alpha is 3 db down from its low frequency value is calculated. This is $f_{c\alpha}$.

For alloyed junction transistors the method of fabrication usually leads to a geometry in which the base layer does not have plane parallel faces. Therefore, the base width varies over the crosssection, and it is impossible to assign a unique value to the base width, a, in (1). In order to take account of this variation in base width, consider first that two one-dimensional transistors are connected in parallel. These are assumed to be identical in all respects, except that they have different base widths W_1 and W_2, and different areas, A_1 and A_2. Since the currents are on a per unit area basis, the total collector current of this structure is:[4]

$$\begin{aligned} I_c = &\left[J_{nc}(A_1 + A_2) + J_{pc}\left(A_1 \coth \frac{W_1}{L_p}\right.\right. \\ &\left.\left.+ A_2 \coth \frac{W_2}{L_p}\right)\right]\left(\exp \frac{qV_c}{kT} - 1\right) \\ &= J_{pe}\left(A_1 \operatorname{csch} \frac{W_1}{L_p}\right. \\ &\left.+ A_2 \operatorname{csch} \frac{W_2}{L_p}\right)\left(\exp \frac{qV_e}{kT} - 1\right). \end{aligned} \tag{2}$$

Similarly, the total emitter current is:

$$\begin{aligned} I_e = &\left[J_{ne}(A_1 + A_2) + J_{pe}\left(A_1 \coth \frac{W_1}{L_p}\right.\right. \\ &\left.\left.+ A_2 \coth \frac{W_2}{L_p}\right)\right]\left(\exp \frac{qV_e}{kT} - 1\right) \\ &- J_{pc}\left(A_1 \operatorname{csch} \frac{W_1}{L_p}\right. \\ &\left.+ A_2 \operatorname{csch} \frac{W_2}{L_p}\right)\left(\exp \frac{qV_c}{kT} - 1\right). \end{aligned} \tag{3}$$

Here it has been assumed that we are dealing with an N-type structure, and the currents are taken into the transistor.

It is now possible to calculate

$$\alpha = -\left.\frac{\partial I_c}{\partial I_e}\right|_{V_e}.$$

* Decimal classification: R282.12. Original manuscript received by the Institute, Oct. 14, 1952.

† Philco Corp., Research Div., Philadelphia, Pa.

[1] W. Shockley, M. Sparks and G. K. Teal, "*PN* junction transistors," *Phys. Rev.*, vol. 83, p. 151; 1951.

[2] E. L. Steele, "Theory of alpha for *p-n-p* diffused junction transistors," Proc. I.R.E., vol. 40, pp. 1424–1428; 1952.

[3] For definitions see R. F. Schwarz and J. F. Walsh, "List of Symbols," p. 1720; this issue.

[4] R. F. Schwarz and J. Walsh, Proc. I.R.E., pp. 1715–1720, this issue.

Inserting (2) and (3) into this definition of α, we get

$$\alpha = \frac{\dfrac{A_1 \operatorname{csch} \dfrac{W_1}{L_p} + A_2 \operatorname{csch} \dfrac{W_2}{L_p}}{A_1 \coth \dfrac{W_1}{L_p} + A_2 \coth \dfrac{W_2}{L_p}}}{1 + \dfrac{J_{ne}}{J_{pe}} \dfrac{A_1 + A_2}{A_1 \coth \dfrac{W_1}{L_p} + A_2 \coth \dfrac{W_2}{L_p}}}. \tag{4}$$

Consider the denominator of this expression, and assume that $W_1/L_p \ll 1$ and $W_2/L_p \ll 1$. The denominator becomes

$$\text{denom} = 1 + \frac{J_{ne}}{J_{pe}} \frac{A_1 + A_2}{A_1 \dfrac{L_p}{W_1} + A_2 \dfrac{L_p}{W_2}} \doteq 1. \tag{5}$$

As will be shown later, the value of this denominator for surface-barrier transistors is very nearly unity. If it is now assumed that a small a-c variation of radian frequency ω is superimposed on the direct voltages applied to the transistor, it can be shown[5] that the only change in the equations is that L_p must be replaced by $L_p(1+i\omega\tau_p)^{-1/2}$, where τ_p is the lifetime of holes in the base. From (4) and (5), then, the entire frequency variation of alpha is contained in the numerator of (4). If we call this numerator β, and again assume $W_1/L_p \ll 1$, $W_2/L_p \ll 1$, we get

$$\beta = \frac{\dfrac{A_1}{W_1} + \dfrac{A_2}{W_2}}{\dfrac{A_1}{W_1} + \dfrac{A_2}{W_2} + \dfrac{i\omega}{2D_p}(A_1W_1 + A_2W_2)}. \tag{6}$$

This is 3 db down from its low frequency value when the real and imaginary parts of the denominator are equal. Therefore,

$$\omega_{c\alpha} = 2D_p \frac{\dfrac{A_1}{W_1} + \dfrac{A_2}{W_2}}{A_1W_1 + A_2W_2}. \tag{7}$$

[5] E. L. Steele, *op. cit.*, (23).

It is now possible to go through precisely the same derivation for N transistors in parallel, where again these differ only in their areas and base widths. The results are

$$\beta = \frac{\sum_{n=1}^{N} \dfrac{A_n}{W_n}}{\sum_{n=1}^{N} \dfrac{A_n}{W_n} + \dfrac{i\omega}{2D_p} \sum_{n=1}^{N} A_nW_n} \tag{8}$$

and

$$\omega_{c\alpha} = 2D_p \frac{\sum_{n=1}^{N} \dfrac{A_n}{W_n}}{\sum_{n=1}^{N} A_nW_n}. \tag{9}$$

These sums may be generalized to integrals, for the case of a continuously varying base width.

In order to obtain numerical results, consider a circularly symmetrical transistor, with a cross section as shown in Fig. 1. Such a shape is chosen, since it is found experimentally that most transistors have this dished shape. In this case, we assume that for $r < R_1$, $W = a$ and for $R_1 < r < R_2$, $W = a + b(r - R_1/R_2 - R_1)^2$. Thus, if we generalize (9) to the integral form, we get

$$\omega_{c\alpha} = 2D_p \frac{\displaystyle\int_0^{R_1} \frac{2\pi r dr}{a} + \int_{R_1}^{R_2} \frac{2\pi r dr}{a + b\left(\dfrac{r - R_1}{R_2 - R_1}\right)^2}}{\displaystyle\int_0^{R_1} 2\pi r a dr + \int_{R_1}^{R_2} \left[a + b\left(\frac{r - R_1}{R_2 - R_1}\right)^2\right] 2\pi r dr}. \tag{10}$$

Upon carrying out the integrations and letting $R_2/R_1 = k$, the final result is

$$\omega_{c\alpha} = \frac{2D_p}{a^2} \frac{1 + \dfrac{a}{b}(k-1)^2 \ln \dfrac{a+b}{a} + 2(k-1)\sqrt{\dfrac{a}{b}} \arctan \sqrt{\dfrac{b}{a}}}{k^2 + \dfrac{b}{a} \dfrac{2}{(k-1)^2}\left[\dfrac{k^4}{4} - \dfrac{2k^3}{3} + \dfrac{k^2}{2} - \dfrac{1}{12}\right]} = \frac{2D_p}{a^2} K. \tag{11}$$

The function K is plotted vs $a+b/a$ in Fig. 2, with k as a parameter.

The effect of a varying base width can be quite substantial, even for relatively small departures from uniformity. For example, for $a+b/a=2$ and $k=1.5$, the alpha cutoff frequency will be only 70 per cent of that predicted by the simple theory. A significant point to be kept in mind is that (8) and (9), which involve only properties of the base, as well as the fundamental (2) and (3), will apply in any arrangement where minority carriers move through the base by diffusion, and this is true of surface-barrier transistors as well as grown and alloyed junction types.[6]

[6] R. F. Schwarz and J. F. Walsh, Proc. I.R.E., pp. 1715–1720, this issue.

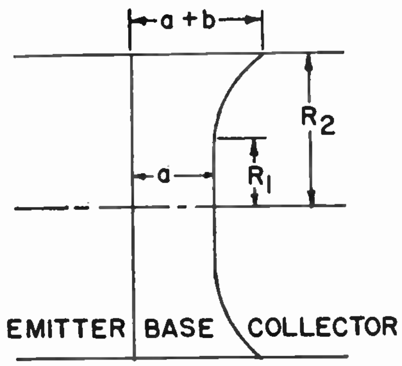


Fig. 1—Idealized transistor geometry.

Experimental Results

In order to check the theoretical results derived in Part I, several units were made by the jet electrolytic etching and plating technique described in the companion papers, purposely varying the base width. The material used was 1.1 ohm-cm N-type germanium, which had a minority-carrier lifetime of about 70 μsec. Emitter and collector were .0025 inch in diameter, contact was made to them by .0014 inch diameter wires.

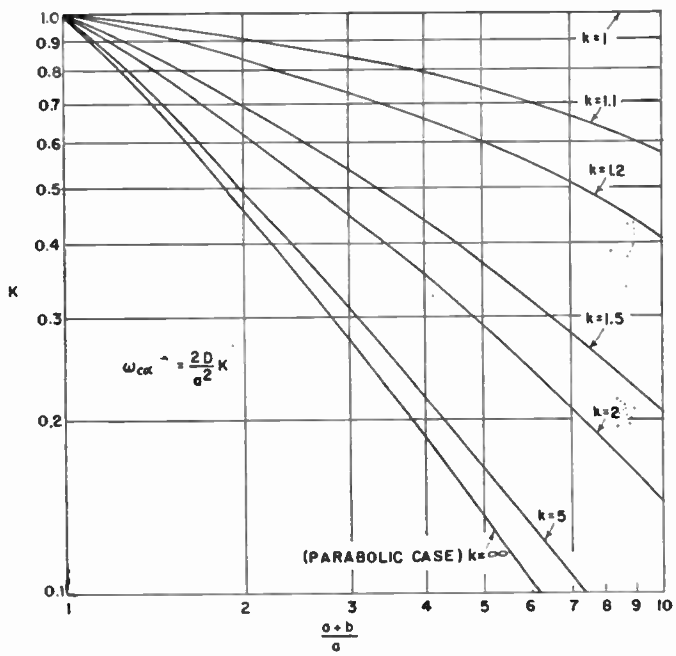


Fig. 2—Reduction of alpha cutoff by non-planar base region.

Complete electrical measurements were then made on the units. Following this, they were embedded in a thermosetting resin. After the resin had hardened, the units were ground down and polished to expose a cross-section through the axis of the unit. A tracing taken from a photomicrograph of unit No. 3 is shown in Fig. 3. The pertinent parameters for three experimental units are presented in Table I. The estimated accuracy for the measured alpha cutoff frequency is ± 2 mc; for that calculated it is ± 10 per cent. In finding the value of K from Fig. 2, it is assumed that $k=\infty$. Ratio of minimum base width to diffusion length in widest-spaced unit is only 0.024. This justifies the assumption in (5).

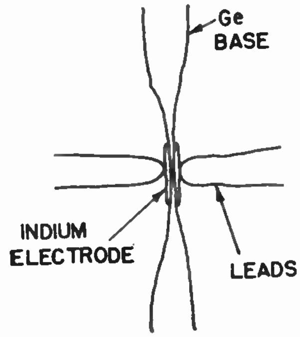


Fig. 3—Tracing of photomicrograph of experimental surface-barrier transistor #3.

Also included in Table I is the frequency of alpha cutoff which would be calculated using the simpler result given in (1). It is seen that as the ratio of maximum to minimum base widths goes up, the discrepancy between this value and that actually achieved experimentally becomes larger quite rapidly. This emphasizes again the importance of making base region as flat as possible when designing for higher frequencies.

TABLE I

Unit No.	$f_{c\alpha}$-mc meas.	α_0 meas.	a-min. base width-mils	$a+b$-max. base width-mils	$f_{c\alpha}$-mc calc.	$D/\pi a^2$ mc
1	12	.80	.52	.66	11	14
2	23	.89	.30	.45	28	43
3	35	.91	.21	.37	33	61

Conclusions

Several restrictions must be kept in mind in applying these results. The analysis is strictly valid first, only when the emitter and collector are coaxial and have the same diameter, and second, only when there is no sidewise component of current. These restrictions apply because the analysis is still essentially one-dimensional, i.e., each element of area is assumed to be a one-dimensional transistor. The restriction to longitudinal current flow in turn implies that surface recombination is negligible. Undoubtedly these assumptions are not rigorously true for a practical transistor. Nevertheless, it is expected that they are sufficiently valid for surface-barrier transistors, (described in accompanying articles) to make this method useful for calculating $f_{c\alpha}$.

Acknowledgment

It is a pleasure to acknowledge the assistance of John Roschen and Joseph DeCristafaro, who did the experimental work reported here.

Part V—The Properties of Metal to Semiconductor Contacts*

R. F. SCHWARZ† AND J. F. WALSH†

Introduction

With the electrochemical techniques described in the accompanying articles it has been possible to obtain consistently metal to semiconductor contacts whose current-voltage characteristics closely approximate the equations of an ideal rectifier. Such characteristics have rarely been observed for metal to semiconductor contacts. A study of diodes made by these techniques has been undertaken with particular emphasis placed on their efficiency as emitters. The results indicate that the efficiency of the diodes as hole injectors is lower than that usually considered desirable for transistor application. However, since the dimensions of the transistors can be quite accurately controlled by these techniques, it will be shown that the hole injection can be enhanced until it is high enough to have a useful value.

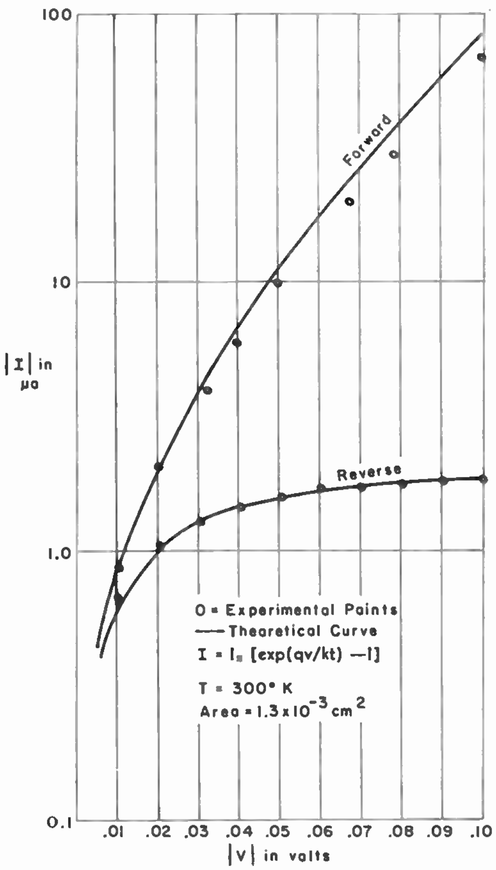


Fig. 1—A comparison of the current-voltage characteristics of an indium plated diode with those of an ideal rectifier. The resistivity of the germanium is 4.9 ohm cm, and the lifetime of the holes is 70 μsec.

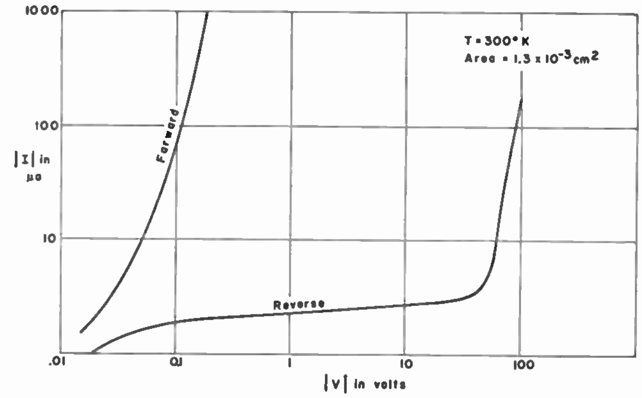


Fig. 2—The current-voltage characteristics of the indium plated diode of Fig. 1 shown over the entire voltage range.

Experimental $I-V$ Curves

Figs. 1 and 2 show typical $I-V$ curves for an indium plated diode. Similar curves have been obtained with a variety of metals. In particular, the tin and cadmium curves appear almost identical to the indium curves.

The current-voltage equation of the indium plated contact is seen to be of the form[1]

$$J = J_s[\exp (qV/kT) - 1] \tag{1}$$

provided V is sufficiently small. Above 0.05 v, the forward curve begins to deviate slightly from this form (1) in a manner very similar to that of the junctions made by alloying indium into comparable n-type material. In fact, there are only two apparent differences between the $I-V$ curves of the plated diodes and the alloyed junctions. The reverse currents of the plated diodes on the average do not saturate quite as well as the alloyed junctions and their reverse current densities at any given point are on the average somewhat higher than in alloyed junctions. However, these diodes consistently follow (1) surprisingly well compared to point-contact curves which usually require a constant less than q/kT in the exponent of (1).

* Decimal classification: R282.12. Original manuscript received by the Institute, Oct. 14, 1953.

† Philco Corp., Research Div., Philadelphia, Pa.

[1] For definitions see list of symbols, page 1720.

The Shape and Capacity of the Barrier for Metal-Semiconductor Contacts

Capacity of the Barrier

Let us assume that a barrier exists at the germanium metal interface, as shown in Fig. 3(a). Let Φ, the electron potential, correspond to the bottom of the conduction band. Under equilibrium conditions, the density of electrons at any point in the barrier is given by[2]

$$n = N_d \exp \frac{-q(\Phi - \Phi_e)}{kT}. \tag{2}$$

The density of holes at any point is given by

$$p = N_d \exp \frac{q(\Phi - \Phi_0 + \Phi_e)}{kT}. \tag{3}$$

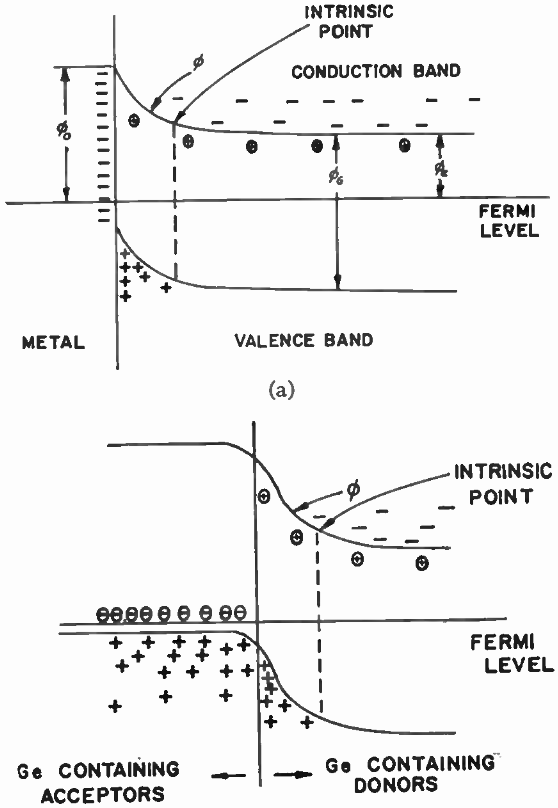
For Φ equal to $\Phi_0/2$, the electron density is equal to the hole density. If the barrier height Φ_0 is greater than $\Phi_0/2$, the density of holes in the germanium near the metal interface will exceed the density of electrons. Thus there will be a small p region in the n-type Ge, although this region is not due to impurity centers, but due to some valence electrons having been transferred to the metal in the process of forming the barrier.[3] An analogous situation should occur in an abrupt P-N junction formed by joining highly doped p-type Ge to less highly doped n-type Ge. (See Fig. 3(b).) In this case the requirement of zero net charge in the space-charge region forces most of the potential barrier to occur in the germanium containing n-type impurities, thus causing the electron potential to rise above $\Phi_0/2$ in the region where the donor impurities occur.[4] Between the point where the potential rises above $\Phi_0/2$ and the interface of the two materials a region containing predominantly positive charge carriers exists in the n-type material.

For an ideal P-N junction, the density of electrons and holes throughout the space-charge region as a function of applied voltage, V, is given by[2]

$$n = N_d \exp \frac{-q(\Phi - \Phi_e - V)}{kT} \tag{4}$$

$$p = N_d \exp \frac{q(\Phi - \Phi_0 + \Phi_e)}{kT}. \tag{5}$$

Here the top of the barrier is held fixed as the applied voltage is varied, and V positive corresponds to the positive potential being applied to the p region. Under these conditions, the right hand side of the potential curve, Φ, is changed by V. Thus (independent of the applied voltage), the electron density is always maintained constant to the right of the space-charge region and the hole density is maintained constant to the left of the space-charge region.



(b)

Fig. 3—A schematic diagram of the barrier (a) for a metal to semiconductor contact, and (b) for an alloyed P-N junction.

Let us assume that (4) and (5) also apply to the metal-semiconductor barrier depicted in Fig. 3(a). Then the shape of the barrier may be determined from Poisson's equation in one dimension:

$$\frac{d^2\Phi}{dx^2} = \frac{4\pi q}{\kappa}[N_d + p - n]$$
$$= \frac{4\pi q N_d}{\kappa}\left[1 + \exp\frac{q(\Phi - \Phi_0 + \Phi_e)}{kT} - \exp\frac{-q(\Phi - \Phi_e - V)}{kT}\right]. \tag{6}$$

This equation is subject to the boundary conditions that

$$\frac{d\Phi}{dx} = 0 \quad \text{when} \quad \Phi = \Phi_e + V$$

and $\Phi = \Phi_0$ when $x = 0$ (the metal-semiconductor interface).

[2] W. Shockley, "Electrons and Holes in Semiconductors," D. Van Nostrand, Inc., New York, N. Y.; 1950. These equations are in a different form from those given by Shockley, but may be shown to be equivalent if the relation

$$N_d = \frac{2(2\pi mkT)^{3/2}}{h^3} \exp \frac{(-q\Phi_e)}{kT}$$

is assumed. For the temperature and resistivity range in which we deal, this equation is valid to within 1 per cent.

[3] We use the designation "n (or p) type" to indicate the characteristic of the semiconductor due to its impurity content, and the designation "n (or p) region," to indicate the type of the majority carriers.

[4] This may be seen by solving Poisson's equation for the electron potential Φ, first in the region containing n-type impurities, then in the region containing p-type impurities and matching the slope at the boundary between the two regions. Matching the slope at this point insures a total net charge of zero in the space charge region. Once this has been accomplished, the value of Φ at the interface between the two regions is automatically determined.

A solution to (6) which satisfies these boundary conditions is

$$x = \sqrt{\frac{\kappa}{8\pi q N_d}} \int_{\Phi}^{\Phi_0} \frac{d\Phi'}{\left[\Phi' - \Phi_e - V - \frac{kT}{q}\left(1 - \exp\frac{-q(\Phi' - \Phi_e - V)}{kT}\right) + \frac{kT}{q}\left(\exp\frac{q(\Phi' - \Phi_g + \Phi_e)}{kT} - \exp\frac{q(2\Phi_e - \Phi_g + V)}{kT}\right)\right]^{1/2}}. \quad (7)$$

Graphs of x as a function of Φ may be obtained by numerically integrating (7). Curves for various voltages are shown in Fig. 4, page 1718, where Φ_0 has been taken as 0.6 v and the resistivity of the Ge is taken as 5 ohm cm. This corresponds to Φ_e equal to 0.29 v.

Differentiating this result with respect to the voltage. The total number of donors per unit cross-sectional area, which are not neutralized by electrons, is given by

$$N = \int_0^\infty (N_d - n)dx. \quad (8)$$

The capacitance per unit area of the barrier is thus

$$C = q\frac{dN}{dV} = \sqrt{\frac{qN_d\kappa}{8\pi}} \frac{d}{dV} \int_{\Phi_e+V}^{\Phi_0} \frac{\left(1 - \exp\frac{-q(\Phi - \Phi_e - V)}{kT}\right)d\Phi}{\left[\Phi - \Phi_e - V - \frac{kT}{q}\left(1 - \exp\frac{-q(\Phi - \Phi_e - V)}{kT}\right) + \frac{kT}{q}\left(\exp\frac{q(\Phi - \Phi_g + \Phi_e)}{kT} - \exp\frac{q(2\Phi_e - \Phi_g + V)}{kT}\right)\right]^{1/2}}. \quad (9)$$

Originally it was hoped that the height of the barrier Φ_0 could be obtained from capacitance measurements. However, if the barrier is sufficiently high it will be shown that its capacitance is relatively insensitive to the barrier height, and is determined almost solely by the resistivity of the Ge.[5] Nevertheless, capacitance measurements can put a lower limit on the barrier height and in addition provide a check on (7) since it involves the detailed shape of the barrier.

Let us suppose that a positive bias is applied across the barrier. The steady-state charge distribution will change in three ways.

1. There will be fewer electrons on the surface of the metal.
2. There will be more holes (or less electrons) in the valence band.
3. There will be more electrons in the conduction band.

The loss of electrons in the first two cases must equal the addition of electrons in the third case, and this transfer in the steady-state charge distribution represents a capacitance. This capacitance may be calculated by computing the change in the number of electrons in the conduction band with applied voltage. Since the donors do not move with applied voltage, this is equivalent to computing the number of donors that are not neutralized by conduction electrons and then differenti-

[5] The problem of the capacitance of the metal-semiconductor contact with a high barrier is essentially the same as the channel effect capacitance in W. L. Brown, "*N-P-N* Transistors," *Phys. Rev.*, vol. 91, p. 518; 1953.

The latter equality has been obtained from (4), (5), and (8). The capacity of a barrier with uniform impurity concentration is usually accepted as being of the form

$$C = \sqrt{\frac{qN_d\kappa}{8\pi} \frac{1}{(-V + U)}} \quad (10)$$

where U represents $(\Phi_0 - \Phi_e)$, a constant.

Equation (9) has been numerically integrated for 5 ohm-cm material with reverse biases between 0.1 v and 10 v. The results of the calculations may best be expressed in the form given in (10) where U is now voltage dependent. Graphs of U vs. V for various values of $(\Phi_0 - \Phi_e)$ are in Fig. 5, page 1718. For $\Phi_0 - \Phi_e$ less than or equal to $(\Phi_g - 2\Phi_e)$, U is essentially constant and equal to $(\Phi_0 - \Phi_e - kT/q)$. For $\Phi_0 - \Phi_e$ large compared to $\Phi_g - 2\Phi_e$, U is voltage dependent, but not very sensitive to $\Phi_0 - \Phi_e$ in the low voltage range. For voltages large compared to U, the capacity will be insensitive to U. Therefore, if a high barrier exists, the exact height of the barrier cannot be determined from capacitance measurements.

A Wayne-Kerr bridge was employed to determine the capacity of the diodes. The stray capacity and the capacity of the mounting system were measured and subtracted from the measured value of the entire system. The alternating voltage signal was at most 1/100 of the bias voltage. Measurements were made from frequencies of 600 kc to 2 mc and no frequency dependence was observed. It is felt that the measured capacities are accurate to within $\pm 0.5\ \mu\mu f$.

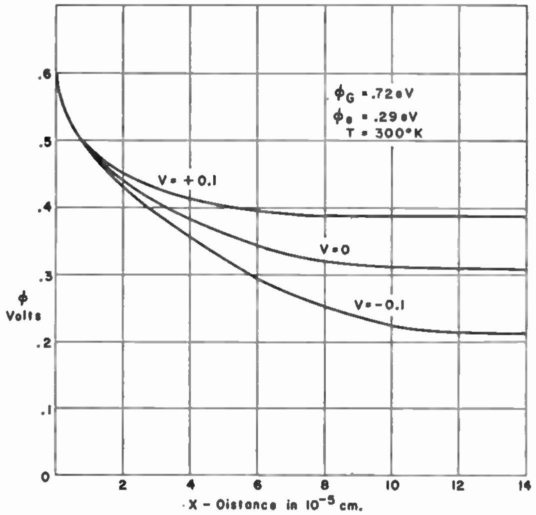


Fig. 4—Shape of barrier for $V=+0.1$, 0, and -0.1 volts.

A typical set of data for an indium-plated diode is shown in Fig. 6.[6] In the same figure a graph is shown of the log of the measured capacitance vs. log $(-V+U)$, where U has been taken from Fig. 5 for $\Phi_0-\Phi_e$ equal to 0.30. This latter curve is a straight line whose slope is equal to -0.50 ± 0.01. This is the value of the slope to be expected if (9) is correct. A plot of log C vs. log $(-V+U)$ for $\Phi_0-\Phi_e$ equal to 0.15 also yields a straight

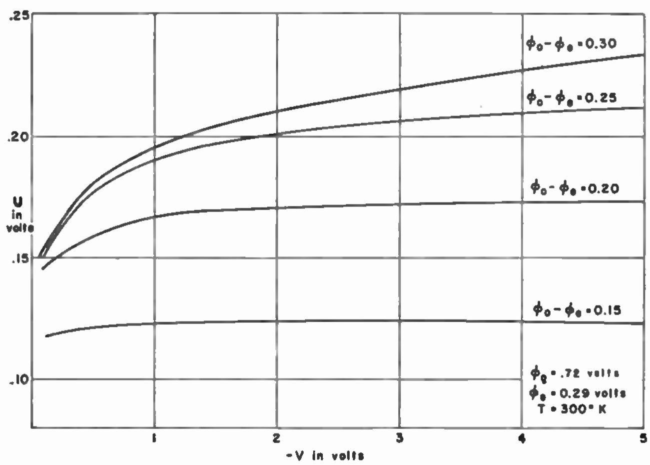


Fig. 5—Theoretical curves of the voltage vs. U, as defined in (10), with the barrier height as a parameter. These curves apply only to germanium with a resistivity of approximately 5 ohm-cm.

line, but its slope is calculated as -0.48 ± 0.01. From this we may conclude that the barrier height Φ_0 is greater than 0.44 v. For a barrier height of 0.43 v, the hole density is equal to the donor density. It therefore appears that the hole density near the interface of the metal is greater than the electron density in the bulk of the Ge. The empirical value of $\sqrt{q\kappa N_a/8\pi}\ X$ area determined from Fig. 6, is 10 $\mu\mu$f (volts)$^{1/2}$. Compare this with a theoretical value of 7.2 $\mu\mu$f (volts)$^{1/2}$. We conclude effective area of the barrier is the same order of magnitude as the macroscopic plated area of contact.

[6] The capacitance at 0.1 v on all units measured fell somewhat higher than is theoretically predicted. This may be explained by the parallel capacitance (such as occurs in P-N junctions) in the region beyond the space charge. This capacitance falls off exponentially with the voltage, but should be of the order of ½ $\mu\mu$f at 0.1 v for these diodes. Shockley, *op. cit.*, p. 316.

P-N junctions made by alloying indium into 5Ω-cm n-type Ge yielded essentially the same variations of capacitance with voltage as the plated contacts. Thus (9) predicts the correct capacitance, both for abrupt indium diffused P-N junction and the plated contacts. It appears that the detailed shape of the barrier (or the distribution of carriers) as a function of the applied voltage is not very different in the two cases, although no apparent modification of the germanium crystal beneath the surface is involved in the plated contact.

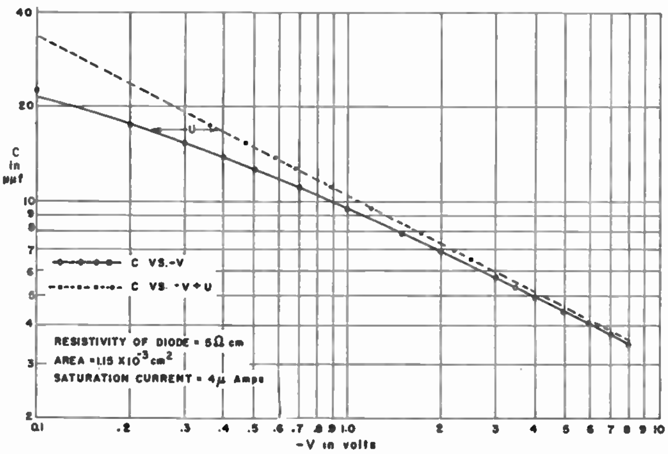


Fig. 6—A plot of the experimental capacitance of an indium plated diode vs. the applied voltage, and also the experimental capacitance vs. the applied voltage plus U. U was taken for $(\Phi_0-\Phi_e)$ equal to 0.30.

Let us return to (5) for the hole density as a function of applied voltage. The capacity measurements verify this equation only near the metal interface, since (in the capacity calculations) its value rapidly becomes unimportant as we move away from the metal. However, it is usually assumed to be valid throughout the space-charge region in P-N junction theory, and from the above considerations it should be equally valid in the case of the metal to semiconductor contacts. In what follows we will assume that this equation is valid. Hence from (3) and (5), the value of p at the edge of the space charge region is taken as

$$p = p_n \exp qV/kT. \tag{11}$$

Here p_n is the equilibrium density of holes in the bulk of the Ge.

The Hole Current

The hole current outside the space-charge region is given by

$$J_p = -q\mu_p pE - kTu_p\frac{dp}{dx} \tag{12}$$

where p is the density of holes at the point x. The first term on the right of (12) represents current due to the electric field, and the second term current due to diffusion. The hole current will be mostly diffusion current if the magnitude of the second term on the right of (12) is much larger than the first term, i.e., if

$$\left|\frac{dp}{dx}\right| \gg \left|\frac{qpE}{kT}\right|. \tag{13}$$

Since the electric field is practically constant outside the space-charge region

$$E \cong \rho J = \rho J_s[\exp(qV/kT) - 1].$$

The latter equality is obtained from (1). Thus (13) becomes

$$\left|\frac{dp}{dx}\right| \gg \left|\frac{qp\rho J_s[\exp(qV/kT) - 1]}{kT}\right|. \tag{14}$$

If this condition is satisfied, then from the continuity equation and (11)

$$p = p_n[\exp(qV/kT) - 1]\exp(-x/L_p) + p_n$$

where x is taken as zero at the edge of the space-charge region in the n material. If (x/L_p) is very close to unity, which is the region of interest for transistors, then

$$p \cong p_n \exp[qV/kT] \text{ and } \frac{dp}{dx} \cong -\frac{p_n}{L_p}[\exp(qV/kT) - 1].$$

Thus it is possible for condition (14) to be satisfied if

$$\delta = \frac{qL_p\rho J_s}{kT}\exp qV/kT \ll 1. \tag{15}$$

For the particular unit shown in Figs. 1 and 2, (15) becomes

$$\delta = 0.016 \exp(qV/kT).$$

Thus δ is less than 0.016 for reverse biases and is less than 0.11 for forward biases below 0.05 v. In this voltage range the hole current should be mostly diffusion current.

For forward biases larger than 0.05 v, appreciable changes in resistivity near the barrier would occur due to injection, and the diffusion length of the carriers and the resistivity could no longer be considered independent of voltage.

If the entire hole current is taken as diffusion current, then just outside the space-charge region

$$J_p = \frac{kT\mu_p}{L_p}p_n[\exp(qV/kT) - 1]$$
$$= J_{ps}[\exp(qV/kT) - 1]. \tag{16}$$

This is the same equation for hole current as is given for P-N junctions.[2] For the diode shown in Figs. 1 and 2, J_{ps} is calculated as 0.23×10^{-3} amps/cm^2. This may be compared with the total saturation current which is about 1.5×10^{-3} amps/cm^2. Thus it appears that approximately 15 per cent of the total current crossing the barrier is carried by holes. This value varied somewhat from diode to diode. On the average it was about 10 per cent for the indium barriers made from 5Ω-cm germanium.

The Electron Current

From (1) and (16) it may be seen that the electron current in the low voltage range is also given by

$$J_n = J_{ns}[\exp(qV/kT) - 1]. \tag{17}$$

Metal semiconductor diode theory predicts that the electron saturation current should be given by[7]

$$J_{ns} = qN_d \exp\cdot\left[\frac{-q(\Phi_0 - \Phi_e)}{kT}\right]\left(\frac{kT}{2m\pi}\right)^{1/2}. \tag{18}$$

The height of the barrier Φ_0 may be calculated from (18). For the diode of Fig. 1 the value of Φ_0 obtained is 0.6 v. No independent measurement of this value has been obtained as yet.

Measurements of J_s at different temperatures are now being made. It is hoped that these measurements will test the validity of the application of (18) to these diodes.

The Surface-Barrier Transistor

As described in the previous articles, the indium plated diodes have been used as emitters and collectors in transistors.

Equation (18), which gives the electron current crossing a diode barrier, is derived on the assumptions that the electron densities outside the space-charge region of the barrier itself are not disturbed by the applied voltage and that they have a Maxwell Boltzmann distribution of velocities relative to the bottom of the conduction band outside the space charge region. In the voltage range specified by (15), these assumptions should not be invalidated by the presence of a second barrier, provided its space-charge region does not overlap that of the first. Thus for base widths several times larger than the space-charge region, the electron current crossing either the emitter or collector of a surface-barrier transistor should be given by (18), where V is the voltage measured across the barrier in question.

On the other hand, the hole current crossing the emitter is seriously affected by the presence of the collector. The density of holes in the n-type material just outside either barrier is determined by (11). Thus, independent of the base widths, a high density of holes exists in the base region near the emitter and a low density of holes exists near the collector. If the base width is made small compared to a diffusion length, the concentration gradient will become large compared to its value in the diode. The smaller the base width, the larger this gradient becomes. Since the hole current is mostly diffusion current, it is proportional to this gradient, and is enhanced by the proximity of the collector to the emitter. These same considerations would apply in P-N-P junction transistors. In fact, (16), (11), the continuity equation, and the above considerations on the electron current are sufficient to show that the current-voltage characteristics of a surface-barrier transistor are of the same form as those of a P-N-P junction transistor.[8]

[7] H. C. Torrey and C. A. Whitmer, "Crystal Rectifiers," McGraw-Hill Book Co., Inc., New York, N. Y.; 1948.
[8] W. Shockley, "The theory of p-n junctions in semi-conductors and p-n junction transistors," *Bell Sys. Tech. Jour.*, vol. 28, p. 435; 1949.

The ac hole injection ratio for a transistor of ideal geometry is

$$\gamma = \frac{1}{1 + \frac{J_{ne}}{J_{pe}} \tanh \frac{W}{L_p}}. \tag{19}$$

In order to demonstrate the enhancement effect of the hole current, some characteristic numbers may be put in this equation. For a diode injection ratio $J_{ps}/J_{ns}+J_{ps}$ equal to 0.1, and a diffusion length L_p equal to 0.06 cm, an injection ratio of .92 can be attained for base widths of 5.8×10^{-4} cm. It has been ascertained by independent means that base widths of this order of magnitude have been attained. It would be difficult to obtain consistently such small base widths in diffused-junction transistors because of the irregularities involved in the alloying process.

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We wish to express our appreciation to many of our colleagues at Philco who have contributed to this work. In particular, we are indebted to M. Flomenhoft for making the capacitance measurements, and to R. Norton for assisting with the calculations. Thanks are also due to E. Borneman and Misses Betty Knoeri and Betty Swenk for the preparation of the diodes.

List of Symbols

A—impedance ratio in neutralizing bridge circuit
a—minimum base width
$a+b$—maximum base width
BW—bandwidth of low-pass amplifier in cps
C—capacitance per unit area of barrier
C_c—collector capacitance
C_N—neutralizing capacitance
D—diffusion constant for minority carriers in base
D_p—diffusion constant for holes in base
e—napierian base
E—electric field
$f_{c\alpha}$—frequency at which $\alpha=0.7\alpha_0$
G_p—power gain, the ratio of load power to actual input power
G_v—voltage gain, the ratio of load voltage to actual input voltage
h—Planck's constant
I_e, I_c—dc emitter and collector currents
i_e, i_c—small-signal emitter and collector currents
J_n—electron current density
J_{nc}—reverse saturation current density of electrons crossing collector
J_{ne}—reverse saturation current density of electrons crossing emitter
J_{ns}—that part of the reverse saturation current density crossing a diode barrier which is carried by electrons
J_p—hole current density outside space-charge region
J_{pc}—reverse saturation current density of holes crossing collector, with the emitter infinitely far away
J_{pe}—reverse saturation current density of holes crossing emitter, with the collector infinitely far away
J_{ps}—that part of the reverse saturation current density crossing a diode barrier which is carried by holes
J_s—reverse saturation current density of a diode
k—Boltzmann's constant
L_p—diffusion length for holes in base
m—effective mass of the electron
N_d—donor density in n-type Ge
p—hole density
p_n—equilibrium density of holes in the n-type material
q—magnitude of electronic charge
r_b, r_c, r_e—small-signal equivalence base, collector, and emitter resistances
r_b'—spreading resistance, the effective hf base resistance
r_b''—r_b-r_b'
r_N—neutralizing resistance
T—absolute temperature
V—voltage applied across barrier
V_c—collector-to-base voltage, collector positive
V_e—emitter-to-base voltage, emitter positive
W—base width in general
X_c—reactance of C_c
Z_c—collector impedance, due to C_c and r_c in parallel
Z_{ij}—open-circuit impedance parameters of a 2-terminal-pair network
α—short-circuit grounded-base current gain, $\partial I_c/\partial I_e|_{V_{cb}}=0$
α_0—lf value of α
γ—ratio of hole current to total current crossing the emitter
κ—dielectric constant for Ge
μ_p—mobility of holes
$\omega_{c\alpha}$—$2\pi f_{c\alpha}$
Φ—electron potential, measured from the Fermi level at zero volts. Its value is taken as Φ_e in the bulk of the Ge under equilibrium conditions, i.e., Φ_e corresponds to the bottom of the conduction band at zero volts
Φ_g—width of the forbidden region in volts
Φ_0—height of the barrier at the metal interface (measured from the Fermi level)
ρ—resistivity of the n-type Ge
τ_p—lifetime for holes in base.

IRE Standards on Antennas and Waveguides: Definitions of Terms, 1953*

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INTRODUCTION

In 1945 "Standards on Radio Wave Propagation—Definitions of Terms Relating to Guided Waves" was first published by the IRE. This was the work of the Technical Committee on Radio Wave Propagation. In 1948 the work of preparing a comprehensive set of standards on Waveguides was delegated to the Technical Committee on Antennas. The Antennas Committee was at this time renamed "Antennas and Waveguides Committee." The following Standards on Waveguides: Definitions of Terms represent a part of a comprehensive set of standards falling in a general classification which includes a revision of the 1945 list. These standards represent the work of the Antennas and Waveguides Committee from 1948 to 1953.

A philosophy was established which would avoid inconsistencies among definitions and allow for interdependencies between definitions. As a specific example it was necessary to decide whether the term "waveguide" or "transmission line" is the more basic. A carefully considered decision was made to regard the transmission line as a special type of waveguide. This made it necessary to adopt the name "uniconductor waveguide" to describe the metal tube structures commonly called "waveguides."

The definitions of terms relating to losses of various kinds such as Heat Loss, Insertion Loss, Reflection Loss, Transition Loss, Return Loss and Transmission Loss all reflect the consistent point of view that loss may be expressed either as a power ratio or as a power difference.

The committee has avoided, wherever possible, the formulation of a definition strictly as the statement of a mathematical formula and has generally favored the more physical picture. Clarity and simplification consistent with general usage has been preferred to completely rigorous and involved definitions which attempt to take into account all conceivable conditions.

* Reprints of this Standard, 53IRE2.S1, may be purchased while available from the Institute of Radio Engineers, 1 East 79 Street, New York 21, N. Y. at $0.75 per copy. A 20-per cent discount will be allowed for 100 or more copies mailed to one address.

Whenever a commonly used term has specialized significance when applied to the field of waveguides this is noted as a parenthetical part of the title. Terms which are italicized in the definitions are all defined in this list.

DEFINITIONS

Artificial Line. A network which simulates the electrical characteristic of a *transmission line.*

Attenuation (in a *Waveguide*). Of a quantity associated with a traveling waveguide wave, the decrease with distance in the direction of propagation.

Note—Attenuation of power is usually measured in terms of db or db per unit length.

Attenuation Band (of a *Uniconductor Waveguide*). *Rejection band.*

Attenuation Constant. Of a *traveling plane wave* at a given frequency, relative rate of decrease of amplitude of a field component (or of voltage or current) in *direction of propagation* in nepers per unit length.

Axial Ratio. The ratio of the major axis to the minor axis of the *polarization ellipse.*

Note—This is preferred to "Ellipticity" because mathematically *ellipticity* is 1 minus the reciprocal of the *axial ratio.*

Balanced Currents (on a *Balanced Line*). Currents flowing in the two conductors of a *balanced line* which, at every point along the line, are equal in magnitude and opposite in direction.

Balanced Line (Two Conductor). A *transmission line* consisting of two conductors in the presence of ground capable of being operated in such a way that when the voltages of the two conductors at all transverse planes are equal in magnitude and opposite in polarity with respect to ground, the currents in the two conductors are equal in magnitude and opposite in direction.

Note—A *balanced line* may be operated under unbalanced conditions and the aggregate then does not form a *Balanced Line System.*

Balanced Line System. A system consisting of generator, *balanced line,* and load adjusted so that the voltages of the two conductors at all transverse planes are equal in magnitude and opposite in polarity with respect to ground.

Note—*Balanced Line System* is frequently shortened to *Balanced Line.* Care should be taken not to confuse this abbreviated terminology with the standard definition of *Balanced Line.*

Balanced Termination. For a system or network having two output terminals, a load presenting the same impedance to ground for each of the output terminals.

Balanced Voltages (on a *Balanced Line*). Voltages (relative to ground) on the two conductors of a *balanced line* which, at every point along the line, are equal in magnitude and opposite in polarity.

Cable. A *transmission line* or group of *transmission lines* mechanically assembled in compact flexible form.

Characteristic Impedance (of a Circular *Waveguide*). For the dominant (TE_{11}) mode of a lossless circular *uniconductor waveguide* at a specified frequency above the *cut-off frequency,* (1) the ratio of the square of the rms voltage along the diameter where the electric vector is a maximum to the total power flowing when the guide is match terminated, (2) the ratio of the total power flowing and the square of the total rms longitudinal current flowing in one direction when the guide is match terminated, (3) the ratio of the rms voltage along the diameter where the electric vector is a maximum to the total rms longitudinal current flowing along the half surface bisected by this diameter when the guide is match terminated.

Note 1—Under definition (1) the power $W = V^2/Z_{(W,V)}$ where V is the voltage, and $Z_{(W,V)}$ the characteristic impedance defined in (1).

Note 2—Under definition (2) the power $W = I^2 Z_{(W,I)}$ where I is the current and $Z_{(W,I)}$ the characteristic impedance defined in (2).

Note 3—The characteristic impedance $Z_{(V,I)}$ as defined in (3) is the geometric mean of the values given by (1) and (2). Definition (3) can be used also below the *cut-off frequency.*

Characteristic Impedance (of a Rectangular *Waveguide*). For the dominant (TE_{10}) mode of a lossless rectangular *uniconductor waveguide* at a specified frequency above the *cut-off frequency,* (1) the ratio of the square of the rms voltage between midpoints of the two conductor faces normal to the electric vector and the total power flowing when the guide is match terminated, (2) the ratio of the total power flowing and the square of the rms longitudinal current flowing on one face normal to the electric vector when the guide is match terminated, (3) the ratio of the rms voltage between midpoints of the two conductor faces normal to the electric vector and the total rms longitudinal current flowing on one face when the guide is match terminated.

Note 1—Under definition (1) the power $W = V^2/Z_{(W,V)}$ where V is the voltage, and $Z_{(W,V)}$ the characteristic impedance defined in (1).

Note 2—Under definition (2) the power $W = I^2 Z_{(W,I)}$ where I is the current and $Z_{(W,I)}$ the characteristic impedance defined in (2).

Note 3—The characteristic impedance $Z_{(V,I)}$ as defined in (3) is the geometric mean of the values given by (1) and (2). Definition (3) can be used also below the *cut-off frequency.*

Characteristic Impedance (of a Two-Conductor *Transmission Line*). For a *traveling transverse electromagnetic wave,* the ratio of the complex voltage between the conductors to the complex current on the conductors in the same transverse plane with the sign so chosen that the real part is positive.

Characteristic Wave Impedance. For a traveling *electromagnetic wave* at a given frequency, the ratio at a point of the complex magnitude of the transverse electric vector to that of the transverse magnetic vector with the sign so chosen that the real part is positive.

Coaxial (or Concentric) Transmission Line. A *transmission line* consisting of two coaxial cylindrical conductors.

Cross Coupling (in a Transmission Medium). A measure of the undesired power transferred from one channel to another.

Cut-off Frequency (of a *Uniconductor Waveguide*). For a given transmission mode in a non-dissipative *uniconductor waveguide*, the frequency below which the propagation constant is real.

Cut-off Wavelength (of a *Uniconductor Waveguide*). The ratio of the velocity of *electromagnetic waves* in free space to the *cut-off frequency*.

Dielectric Waveguide. A *waveguide* consisting of a dielectric structure.

Direction of Propagation. At any point in a homogeneous, isotropic medium, the direction of time average energy flow.

Note 1—In a *uniform waveguide* the direction of propagation is often taken along the axis.

Note 2—In the case of a uniform lossless *waveguide* the direction of propagation at every point is parallel to the axis and in the direction of time average energy flow.

Distributed Constant (for a *Waveguide*). A circuit parameter that exists along the length of a *waveguide*.

Note—For a *transverse electromagnetic wave* on a two-conductor *transmission line*, the distributed constants are series resistance, series inductance, shunt conductance and shunt capacitance per unit length of line.

Dominant Mode of Propagation (Transmission). The *mode of propagation* of the *dominant wave*.

Dominant Wave (in a *Uniconductor Waveguide*). The *electromagnetic wave* which has the lowest *cut-off frequency*.

Electric Field Vector. At a point in an electric field, the force on a stationary positive charge per unit charge.

Note—This may be measured either in newtons per coulomb or in volts per meter. This term is sometimes called the *Electric Field Intensity* but such use of the work field intensity is deprecated since intensity connotes power in optics and radiation.

Electrical Length. The physical length expressed in wavelengths, radians, or degrees.

Electromagnetic Wave. A wave characterized by variations of electric and magnetic fields.

Note—*Electromagnetic waves* are known as radio waves, heat rays, light rays, etc., depending on the frequency.

Elliptically Polarized Wave. At a given frequency an *electromagnetic wave* for which the component of the electric vector in a plane normal to the *direction of propagation* describes an ellipse.

Ellipticity. See note under *Axial Ratio.*

Exponential Transmission Line. A two-conductor *transmission line* whose characteristic impedances vary exponentially with electrical length along the line.

Heat Loss. The part of the *transmission loss* due to the conversion of electric energy into heat.

Incident Wave. In a medium of certain propagation characteristics, a wave which impinges on a discontinuity or a medium of different propagation characteristics.

Input Impedance of a Transmission Line. The impedance between the input terminals with the generator disconnected.

Insertion Loss. 1. The loss in load power due to the insertion of apparatus at some point in a transmission system. It is measured as the difference between the power received at the load before insertion of the apparatus and the power received at the load after insertion. 2. The ratio, expressed in decibels, of the power received at the load before insertion of the apparatus, to the power received at the load after insertion.

Matched Termination (for a *Waveguide*). A termination producing no *reflected wave* at any transverse section of the *waveguide*.

Matched Transmission Line. See *Matched Waveguide.*

Matched Waveguide. A *waveguide* having no *reflected wave* at any transverse section.

Mode of Propagation (Transmission). A form of propagation of guided waves that is characterized by a particular field pattern in a plane transversed to the *direction of propagation*, which field pattern is independent of position along the axis of the *waveguide*.

Note—In the case of *uniconductor waveguides* the field pattern of a particular *mode of propagation* is also independent of frequency.

Mode of Resonance. A form of natural electromagnetic oscillation in a resonator, characterized by a particular field pattern which is invariant with time.

Mode Transducer (Mode Transformer). A device for transforming an *electromagnetic wave* from one *mode of propagation* to another.

Normalized Admittance. The reciprocal of the *normalized impedance*.

Normalized Impedance (with respect to a *waveguide*). An impedance divided by the *characteristic impedance* of the *waveguide*.

Phase Constant. Of a *traveling plane wave* at a given frequency, the space rate of decrease of phase of a field component (or of the voltage or current) in the *direction of propagation* in radians per unit length.

Phase Velocity. Of a *traveling plane wave* at a single frequency, the velocity of an equiphase surface along the *wave normal.*

Polarization Ellipse (of a Field Vector). The locus of positions for variable time of the terminus of an instantaneous field vector of one frequency at a point in space.

Polarization Receiving Factor. The ratio of the power received by an antenna from a given plane wave of arbitrary polarization to the power received by the same antenna from a plane wave of the same power density and *direction of propagation*, whose state of polarization has been adjusted for the maximum received power.

Note—It is equal to the square of the absolute value of the scalar product of the *polarization unit vector* of the given plane wave with that of the radiation field of the antenna along the direction opposite to the *direction of propagation* of the plane wave.

Polarization Unit Vector (for a Field Vector). At a point, a complex field vector divided by its magnitude.

Note 1—For a field vector of one frequency at a point, the *polarization unit vector* completely describes the state of polarization, that is, the *axial ratio* and orientation of the polarization ellipse and the sense of rotation on the ellipse.

Note 2—A complex vector is one each of whose components is a complex number. The magnitude is the positive square root of the scalar product of the vector and its complex conjugate.

Propagation Constant. Of a *traveling plane wave* at a given frequency, the complex quantity whose real part is the *attenuation constant* in nepers per unit length and whose imaginary part is the *phase constant* in radians per unit length.

Push-Pull Currents. *Balanced currents.*

Push-Pull Voltages. *Balanced voltages.*

Push-Push Currents. Currents flowing in the two conductors of a *balanced line* which, at every point along the line, are equal in magnitude and in the same direction.

Push-Push Voltages. Voltages (relative to ground) on the two conductors of a *balanced line* which, at every point along the line, are equal in magnitude and have the same polarity.

Radial Transmission Line. A pair of parallel conducting planes used for propagating uniform circularly cylindrical waves having their axes normal to the planes.

Radiation Loss. That part of the *transmission loss* due to radiation of radio frequency power from a transmission system.

Reflected Wave. When a wave in a medium of certain propagation characteristics is incident upon a discontinuity or a second medium, the wave component that results in the first medium in addition to the *incident wave.*

Reflection Co-efficient (in a Transmission Medium). At a given frequency, at a given point, and for a given mode of transmission, the ratio of some quantity associated with the *reflected wave* to the corresponding quantity in the *incident wave.*

Note—The *reflection co-efficient* may be different for different associated quantities, and the chosen quantity must be specified. The "voltage reflection co-efficient" is most commonly used and is defined as the ratio of the complex electric field strength (or voltage) of the *reflected wave* to that of the *incident wave.*

Reflection Co-efficient (of a Transition or Discontinuity). For a transition or discontinuity between two transmission media, the *reflection co-efficient* at a specified point in one medium which would be observed if the other medium were match terminated.

Reflection Loss. 1. That part of the *transition loss* due to the reflection of power at the discontinuity. 2. The ratio in decibels of the power incident upon the discontinuity to the difference between the power incident upon and the power reflected from the discontinuity.

Refracted Wave. That part of an *incident wave* which travels from one medium into a second medium.

Rejection Band (of a *Uniconductor Waveguide*). The frequency range below the *cut-off frequency.*

Return Loss. 1. At a discontinuity in a transmission system, the difference between the power incident upon the discontinuity and the power reflected from the discontinuity. 2. The ratio in decibels of the power incident upon the discontinuity to the power reflected from the discontinuity.

Sending End Impedance. The *input impedance* of a *transmission line.*

Shielded Pair. A two-wire *transmission line* surrounded by a metallic sheath.

Shielded Transmission Line. A *transmission line* whose elements essentially confine propagated electrical energy to a finite space inside a conducting sheath.

Skin Depth. For a conductor carrying currents at a given frequency as a result of the *electromagnetic waves* acting upon its surface, the depth below the surface at which the current density has decreased one neper below the current density at the surface.

Note—Usually the skin depth is sufficiently small so that for ordinary configurations of good conductors, the value obtained for a plane wave falling on a plane surface is a good approximation.

Standing Wave. A wave in which, for any component of the field, the ratio of its instantaneous value at one point to that at any other point does not vary with time.

Standing Wave Loss Factor. The ratio of the *transmission loss* in an unmatched *waveguide* to that in the same *waveguide* when matched.

Standing Wave Ratio. At a given frequency in a *uniform waveguide*, the ratio of the maximum to the minimum amplitudes of corresponding components of the field (or the voltage or current) along the *waveguide* in the *direction of propagation*.

Note—Alternatively, the *standing wave ratio* may be expressed as the reciprocal of the ratio defined above.

Tapered Transmission Line. See *Tapered Waveguide*.

Tapered Waveguide. A *waveguide* in which a physical or electrical characteristic increases continuously with distance along the axis of the guide.

Totally Unbalanced Currents (on a *Balanced Line*). *Push-push currents*.

Transition Loss (Wave Propagation Usage). 1. At a transition or discontinuity between two transmission media, the difference between the power incident upon the discontinuity and the power transmitted beyond the discontinuity which would be observed if the medium beyond the discontinuity were match-terminated. 2. The ratio in decibels of the power incident upon the discontinuity to the power transmitted beyond the discontinuity which would be observed if the medium beyond the discontinuity were match terminated.

Transmission Band (of a *Uniconductor Waveguide*). The frequency range above the *cut-off frequency*.

Transmission Co-efficient (in a Transmission Medium). At a given frequency, at a given point, and for a given *mode of transmission*, the ratio of some quantity associated with the resultant field, which is the sum of the *incident* and *reflected waves*, to the corresponding quantity in the *incident wave*.

Note—The *transmission coefficient* may be different for different associated quantities, and the chosen quantity must be specified. The "voltage transmission coefficient" is commonly used and is defined as the complex ratio of the resultant electric field strength (or voltage) to that of the *incident wave*.

Transmission Co-efficient (of a Transition or Discontinuity). For a transition or discontinuity between two transmission media, at a given frequency, the ratio of some quantity associated with the *transmitted wave* at a specified point in the second medium to the same quantity associated with the *incident wave* at a specified point in a first medium, the second medium being match terminated.

Transmission Line. A *waveguide* consisting of two or more conductors.

Transmission Loss. 1. The power lost in transmission between one point and another. It is measured as the difference between the net power passing the first point and the net power passing the second. See *Standing Wave Loss Factor*. 2. The ratio in decibels of the net power passing the first point to the net power passing the second.

Transmitted Wave. When a wave in a medium of certain propagation characteristics is incident upon a discontinuity or a second medium, the forward traveling wave that results in the second medium.

Note—In a single medium the *transmitted wave* is that wave which is traveling in the forward direction.

Transverse Electric Wave (TE Wave). In a homogeneous isotropic medium, and *electromagnetic wave* in which the *electric field vector* is everywhere perpendicular to the *direction of propagation*.

Transverse Electromagnetic Wave (TEM Wave). In a homogeneous isotropic medium, an *electromagnetic wave* in which both the electric and magnetic field vectors are everywhere perpendicular to the *direction of propagation*.

Transverse Magnetic Wave (TM Wave). In a homogeneous isotropic medium, an *electromagnetic wave* in which the magnetic field vector is everywhere perpendicular to the *direction of propagation*.

Traveling Plane Wave. A plane wave each of whose frequency components has an exponential variation of amplitude and a linear variation of phase in the *direction of propagation*.

Uniconductor Waveguide. A *waveguide* consisting of a cylindrical metallic surface surrounding a uniform dielectric medium.

Note—Common cross-sectional shapes are rectangular and circular.

Uniform Waveguide. A *waveguide* in which the physical and electrical characteristics do not change with distance along the axis of the guide.

Wave Normal. A unit vector normal to an equiphase surface with its positive direction taken on the same side of the surface as the *direction of propagation*. In isotropic media, the wave normal is in the *direction of propagation*.

Waveguide. A system of material boundaries capable of guiding waves.

Waveguide Wavelength. For a *traveling plane wave* at a given frequency, the distance along the guide between points at which a field component (or the voltage or current) differs in phase by 2π radians.

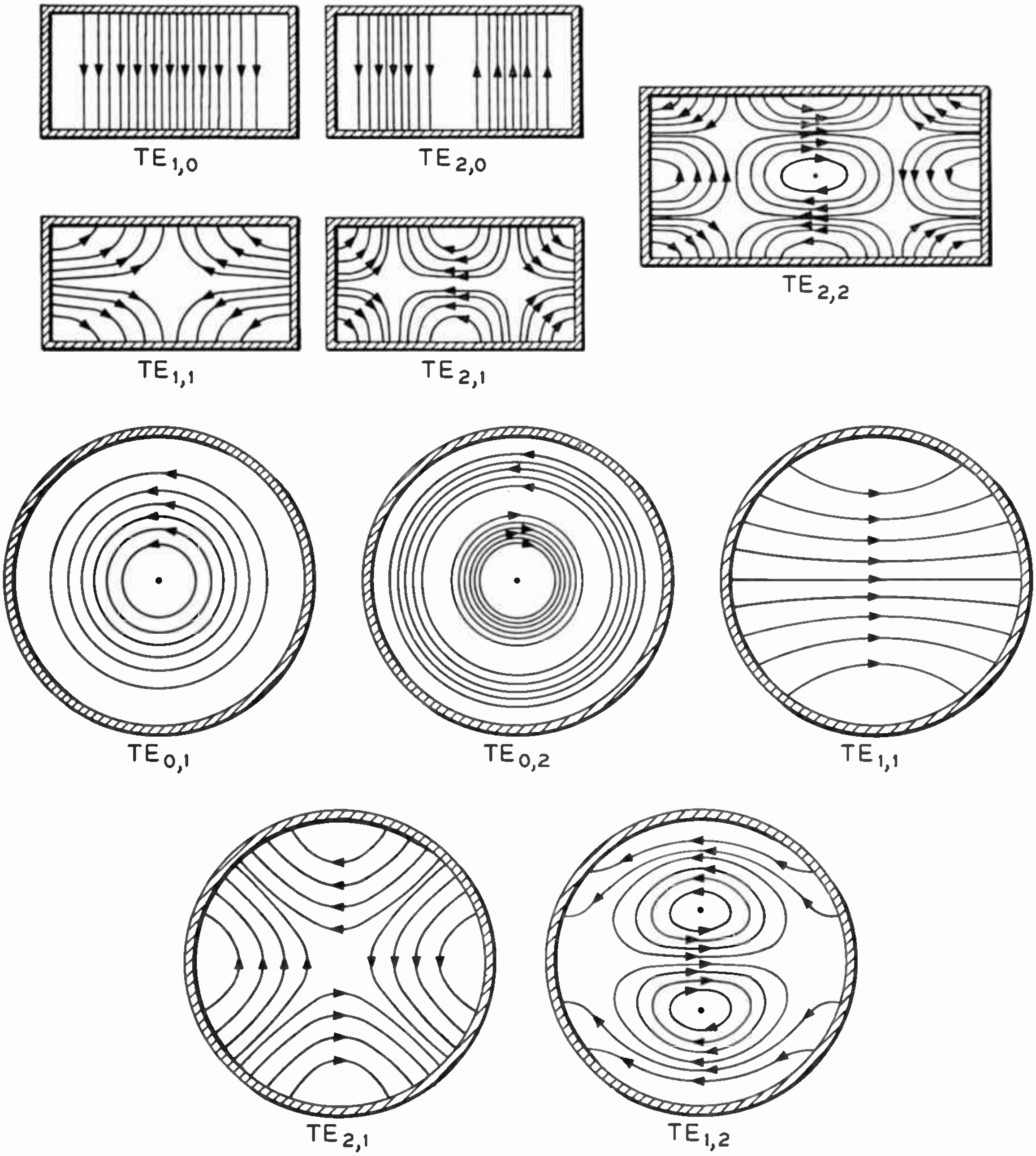

Fig. 1—The E lines for some of the more elementary TE modes in rectangular and circular *waveguides.*

Classification of Waveguide Waves

The waves that can be transmitted by cylindrical *waveguides* may be divided into four classifications:

(1) transverse electric (TE)
(2) transverse magnetic (TM)
(3) transverse electromagnetic (TEM)
(4) hybrid electromagnetic (HEM)

These are defined below. For lossless *uniconductor waveguides*, only the TE and TM waves can be transmitted. For multiconductor *waveguides*, TEM waves may also be transmitted. HEM waves may be transmitted along *dielectric waveguides* and within *waveguides* partially filled with dielectric material.

In the case of *uniconductor waveguides* whose cross-sectional boundary can be represented by constant co-ordinate lines of a co-ordinate system in which the variables of the wave equation are separable, the possible waves are designated by TE or TM followed by two subscripts indicating the appropriate solution in each of the two co-ordinates. The interpretation of the subscripts for *waveguides* of the more usual cross sections is given in the following. Field distributions and *cut-off frequencies* are given for the more important types.

If the cross-section of the *waveguide* does not fulfill the aforementioned requirement, the wave is designated by TE or TM with one numerical subscript starting with the wave that has the lowest *cut-off frequency* as "1" and numbering the remaining waves in the order of increasing *cut-off frequency.*

Transverse Electric Wave (TE Wave). In a homogeneous isotropic medium an *electromagnetic wave* in which

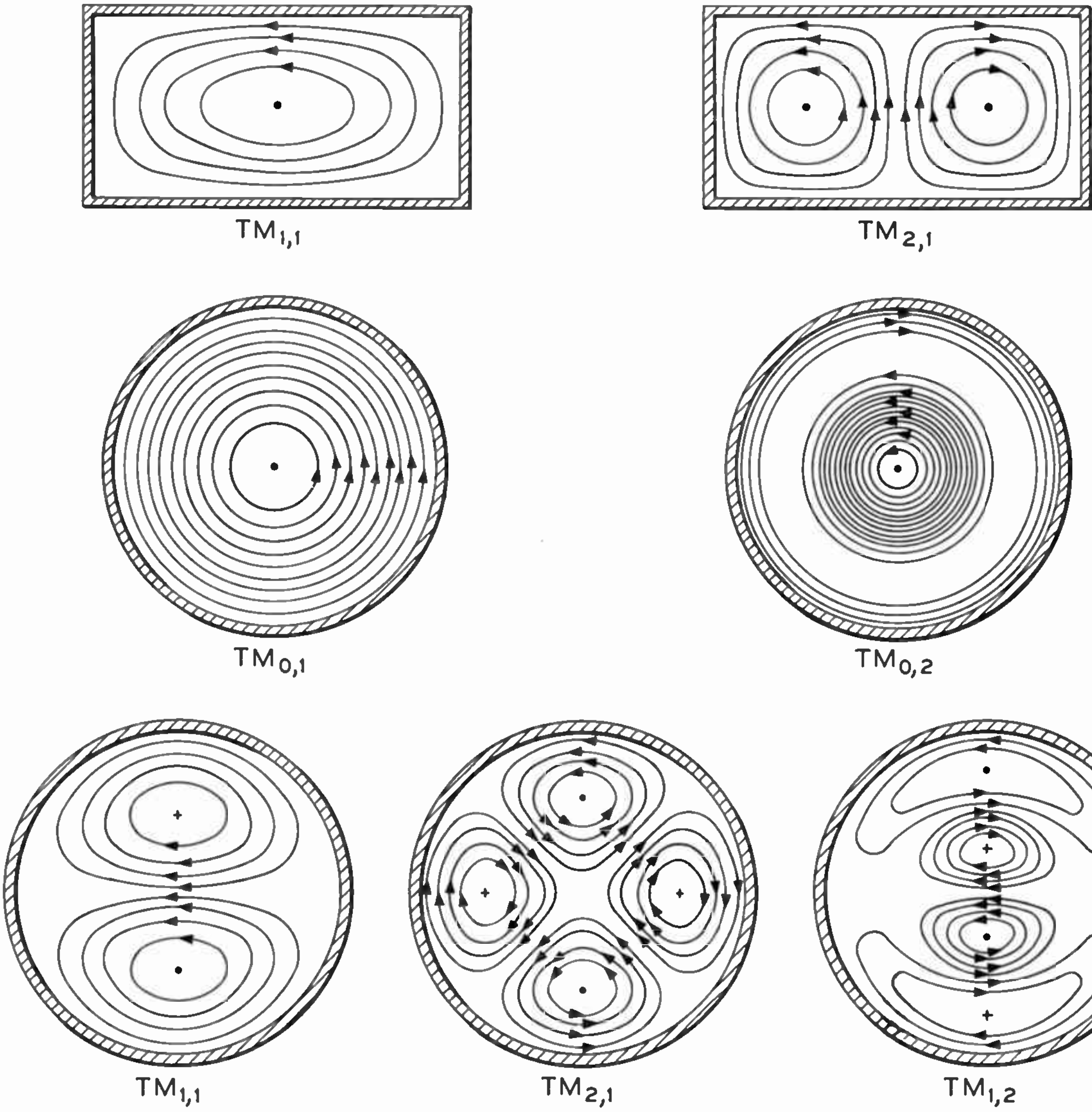

Fig. 2—The H lines for the more elementary TM modes of transmission in rectangular and circular *waveguides*. The resonant wavelengths of cylindrical cavities are given by

$$\lambda_r = 1/\sqrt{(1/\lambda_c)^2 + (l/2c)^2}$$

where λ_c is the *cut-off wavelength* for the transmission mode along the axis, l is the number of half-period variations of the field along the axis and c is the axial length of the cavity.

the *electric field vector* is everywhere perpendicular to the *direction of propagation*.

Transverse Magnetic Wave (TM Wave). In a homogeneous isotropic medium an *electromagnetic wave* in which the magnetic field vector is everywhere perpendicular to the *direction of propagation*.

Transverse Electromagnetic Wave (TEM Wave). In a homogeneous isotropic medium, an *electromagnetic wave* in which both the electric and magnetic field vectors are everywhere perpendicular to the *direction of propagation*.

Hybrid Electromagnetic Wave (HEM Wave). An *electromagnetic wave* having components of both the electric and magnetic field vectors in the *direction of propagation*.

Circular Electric Wave. A *transverse electric wave* for which the lines of electric force form concentric circles.

Circular Magnetic Wave. A *transverse magnetic wave* for which the lines of magnetic force form concentric circles.

Dominant Wave. The guided wave having the lowest *cut-off frequency*. It is the only wave which will carry energy when the excitation frequency is between the lowest *cut-off frequency* and the next higher *cut-off frequency*.

$TE_{m,n}$ Wave in Rectangular Waveguide. In a hollow rectangular metal cylinder, the *transverse electric wave* for which m is the number of half-period variations of the electric field along the longer transverse dimension, and n is the number of half period variations of the electric field along the shorter transverse dimension.

$TM_{m,n}$ Wave in Rectangular Waveguide. In a hollow rectangular metal cylinder, the *transverse magnetic wave* for which m is the number of half-period variations of the magnetic field along the longer transverse dimension, and n is the number of half period variations of magnetic field along the shorter transverse dimension.

Table I gives the ratio of *cut-off wavelengths* to diameters for $TE_{m,n}$ waves in hollow circular metal cylinders:

TABLE I

m=	0	1	2	3	4
n=1	0.820	1.708	1.030	0.748	0.590
n=2	0.448	0.59	0.468	0.382	0.338
n=3	0.309	0.368	0.315	0.277	0.247
n=4	0.2375	0.27	0.24	0.22	0.198
n=5	0.1910	0.21	0.194	0.18	

Table II gives the ratio of *cut-off wavelengths* to diameters for $TM_{m,n}$ waves in hollow circular metal cylinders:

TABLE II

m=	0	1	2	3	4	5
n=1	1.307	0.820	0.613	0.483	0.414	0.358
n=2	0.569	0.448	0.373	0.322	0.284	0.2547
n=3	0.363	0.309	0.270	0.241	0.219	0.200
n=4	0.267	0.2375	0.2127	0.1938		
n=5	0.2106	0.1910	0.1750			

$TE_{m,n}$ Wave in Circular Waveguide. In a hollow circular metal cylinder, the *transverse electric wave* for which m is the number of axial planes along which the normal component of the electric vector vanishes, and n is the number of coaxial cylinders (including the boundary of the *waveguide*) along which the tangential component of electric vector vanishes.

Note 1—$TE_{0,n}$ waves are *circular electric waves* of order n. The TE_{01} wave is the *circular electric wave* with the lowest *cut-off frequency*.

Note 2—The TE_{11} wave is the *dominant wave*. Its lines of electric force are approximately parallel to a diameter.

$TM_{m,n}$ Wave in Circular Waveguide. In a hollow circular metal cylinder, the *transverse magnetic wave* for which m is the number of axial planes along which the normal component of the magnetic vector vanishes, and n is the number of coaxial cylinders to which the electric vector is normal.

Note—$TM_{0,n}$ waves are *circular magnetic waves* of order n. The $TM_{0,1}$ wave is the *circular magnetic wave* with the lowest *cut-off frequency*.

$TE_{m,m,p}$ Resonant Mode in Cylindrical Cavity. In a hollow metal cylinder closed by two plane metal surfaces perpendicular to its axis, the resonant mode whose transverse field pattern is similar to the $TE_{m,n}$ wave in the corresponding cylindrical *waveguide* and for which p is the number of half-period field variations along the axis.

Note—When the cavity is a rectangular parallelopiped, the axis of the cylinder from which the cavity is assumed to be made should be designated since there are three such axes possible.

$TM_{m,n,p}$ Resonant Mode in Cylindrical Cavity. In a hollow metal cylinder closed by two plane metal surfaces perpendicular to its axis, the resonant mode whose transverse field pattern is similar to the $TM_{m,n}$ wave in the corresponding cylindrical *waveguide* and for which p is the number of half-period field variations along the axis.

Note—When the cavity is rectangular parallelopiped, the axis of the cylinder from which the cavity is assumed to be made should be designated since there are three such axes possible.

A Germanium N-P-N Alloy Junction Transistor*

DIETRICH A. JENNY†, ASSOCIATE, IRE

Summary—This paper describes a germanium n-p-n alloy junction transistor which is the counterpart to the germanium p-n-p junction transistor previously described. The importance of this new device arises from a fundamental difference between the two types. In the p-n-p transistor the active charge carriers are positive "holes"; in the n-p-n transistor the active charge carriers are negative electrons. Because these devices operate from power sources of opposite polarity, the two types may be advantageously combined in special circuits to eliminate components and fulfill unusual requirements.[1] Because the electron mobility is more than twice that of holes, one of the factors affecting high-frequency response is more favorable for the n-p-n transistor than for its p-n-p counterpart.

This n-p-n junction transistor is made by fusing a binary lead-antimony alloy into each of the two opposite faces of a thin wafer of *p*-type single-crystal germanium. Since this alloy is ductile, the electrodes may be made relatively large if desired, as there is less danger of introducing differential expansion strains. The techniques and processes of assembly are similar to those employed for p-n-p junction transistors by the alloy process. However, a difference arises from the more uniform penetration afforded by the binary alloy. This leads to more planar junctions and permits better control of junction spacing.

Distribution curves on a typical lot of 100 units are given; best power gain was 45 db, "alpha" 0.997 and 1-kc noise factor, 3 db. High "alpha" is maintained as the collector current is increased.

Introduction

THE n-p-n transistor is distinguished from the p-n-p type by the opposite sign of the active charge carriers which are negative electrons instead of positive holes. This difference manifests itself in the reversal of the operating potentials. This reversal of potentials can be utilized in special circuits which

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† RCA Laboratories Division, Princeton, N. J.

[1] G. C. Sziklai, "Symmetrical properties of transistors and their applications," Proc. IRE, vol. 41, pp. 717–724; June, 1953.

combine both the n-p-n and p-n-p transistors to save components and fulfill special tasks. Because the operating polarities of the n-p-n transistor are the same as those of electron tubes, the n-p-n transistor is well suited to applications where tubes and transistors are incorporated in the same circuit.

The mobility of electrons differs from that of holes in semiconductors; in germanium, mobility is a factor 2.1 higher for electrons than for holes. Although this does not affect the fundamental mechanism of the transistor, it does advantageously influence ultimate high-frequency performance because the diffusion transit time of the minority carriers between the emitter and collector junction is inversely proportional to their mobility. The "alpha" cut-off frequency of the n-p-n transistor is theoretically more than twice as high as that of a geometrically similar p-n-p type, which can be deduced from the following fundamental equation:[2]

$$f = \frac{D}{\pi W^2} = 0.008 \frac{\mu}{W^2} \tag{1}$$

where f is the frequency at which "alpha" squared has dropped to half of its maximum low frequency value. D is the diffusion constant for the minority carriers, μ is their mobility and W is the base section thickness or junction separation. Since (1) shows that the cut-off frequency is proportional to the mobility, the desirability of the higher mobility of electrons as current carriers is obvious. It is also evident that the junction separation must be kept as low as possible for hf transistors.

The n-p-n transistor consists of a thin section of *p*-type germanium between two *n*-type sections. To produce this structure by the alloying technique, *p*-type single crystal germanium is required. The junctions are obtained by alloying the germanium surface with a molten *n*-type impurity from both sides of a thin germanium wafer. Although solid diffusion plays a part at the alloy-germanium interface, the over-all process, which involves a liquid phase, is called "alloying" to distinguish it from the diffusion in the solid state. *N*-Type impurities are, in most cases, solids at room temperature and have to be liquified at elevated temperatures to initiate the alloying process.

The physical principles governing the design of alloy junction transistors have been described previously in connection with the p-n-p junction transistor.[3] The same considerations are applicable to the n-p-n alloy junction transistor so that the following discussion is restricted to problems peculiar to the n-p-n type.

Materials and Alloying Process

Natural sources of germanium yield chiefly *n*-type germanium after reduction of the oxide. Therefore it is necessary to purify the *n*-type material to a purity well above the desired *p*-type impurity concentration. This highly purified germanium is then "doped" in the melt with a suitable *p*-type impurity whose concentration is dictated by the desired germanium resistivity. Gallium and indium have been used successfully for the doping. Transistor theory indicates that it is desirable to use *p*-type single crystal germanium with high lifetime of the minority charge carriers (electrons), preferably in excess of 10 μsec.

The *n*-type impurity element used to form the junction by the alloying process can, in principle, be any of the known ones, such as phosphorus, arsenic, antimony and bismuth. During the work on the n-p-n alloy junction transistor it was found that sulfur, selenium and tellurium are also *n*-type impurities. Extensive tests led to the selection of antimony as most suitable for the alloying impurity. Phosphorus and arsenic are less desirable due to their high vapor pressure; bismuth yields unsatisfactory junctions; and sulfur, selenium and tellurium have high electrical resistivities. Although successful transistors have been made using pure antimony, and small area junctions with antimony give excellent results, considerable difficulty is encountered as the area is increased. Due to the difference in thermal-expansion coefficient between antimony and germanium, severe strains are introduced near the antimony-germanium interface. These differential expansion strains can cause mechanical and electrical instabilities which manifest themselves in one of the three following ways. In the most serious case, the strain forces may be so large that actual breakage occurs and the antimony is separated from the germanium by sudden cleavage of the germanium near the interface. If separation does not take place, there may be internal breaks of microscopic dimensions which cause electrical instabilities due to contact pressure fluctuations and, possibly, fluctuating lattice distortions. In this case, the transistor exhibits random gain fluctuations which are clearly noticeable during a gain measurment. Even if the gain appears to be stable, the strains influence the noise factor considerably and extremely high noise is observed when strains are present.

The elimination or reduction of the differential expansion strains is possible in three ways, namely, by devising an impurity containing material whose thermal expansion coefficient approximates that of germanium, or whose ductility is large, or whose melting point is close to room temperature. Although it does not seem possible to fulfill the above requirements with a single impurity element, there are alloys of two or more phases containing an *n*-type impurity which satisfy one or more of the strain relief conditions. A simple solution is a binary alloy of antimony and a ductile *n*-type or neutral metal which does not interfere with the formation of the junction. Of the many alloys which were investigated, the lead-antimony system was found to be the most successful.

[2] W. Shockley, M. Sparks, and C. K. Teal, "*p-n* junction transistors," *Phys. Rev.*, vol. 83, p. 151; July, 1951.

[3] R. R. Law, C. W. Mueller, J. I. Pancove (Pantchechnikoff) and L. D. Armstrong, "A developmental germanium P-N-P junction transistor," Proc. I.R.E., vol. 40, pp. 1352–1357; Nov., 1952.

In Fig. 1, representing the phase diagram of lead and antimony, a eutectic with a melting point of 252 degrees C. is present at 11.2 per cent antimony. This eutectic is relatively ductile, compared with antimony, and in addition has a considerably lower melting point than pure antimony. It was found that alloys on the antimony-rich side of the eutectic still introduce strains due to the separation of antimony crystallites during the solidification process, so that it is desirable to choose a composition on the lead-rich side. Although similar mechanical properties are exhibited by tin-antimony alloys, the solubility of germanium in tin-rich alloys is considerably more temperature dependent which makes the control of the penetration depth more critical.

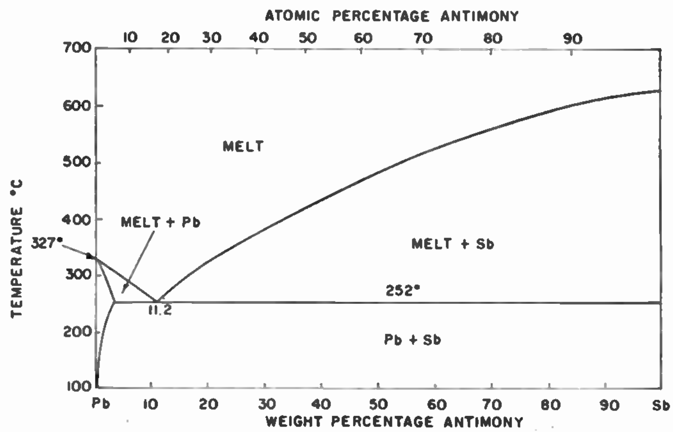

Fig. 1—Phase diagram of the lead-antimony system.

The formation of an alloy junction is governed principally by the following factors: wetting of the germanium by the impurity substance, and solubility of the germanium in the impurity substance. The wetting is dependent on the surface tension of the molten impurity and affects the shape of the junction plane, whereas the solubility determines the penetration depth in addition to having an effect on the junction shape.

Fig. 2 gives the hypothetical characteristic stages during the formation of an alloy junction. As shown in (a) the impurity metal disk is put on the germanium surface and (b) contracts to form a sphere upon melting after which (c) the contact area is enlarged by the wetting process as germanium is being dissolved, and (d) the final configuration is reached after solidification by cooling to room temperature.

As it is desirable to obtain a planar junction, it is preferable that the wetting process take place rapidly and at a low temperature at which the solubility of germanium in the liquid impurity substance is still small. The wetting can be accelerated by exerting mechanical pressure on the impurity substance after melting which helps overcome the surface tension. Because the wetting is accelerated by a low surface tension and the latter is an inverse function of temperature another alternative is to increase the temperature very rapidly during the heating cycle and to process at as high as possible a temperature. Both these methods aid a uniform penetration of the alloy front over the whole junction area and therefore yield more nearly planar junctions.

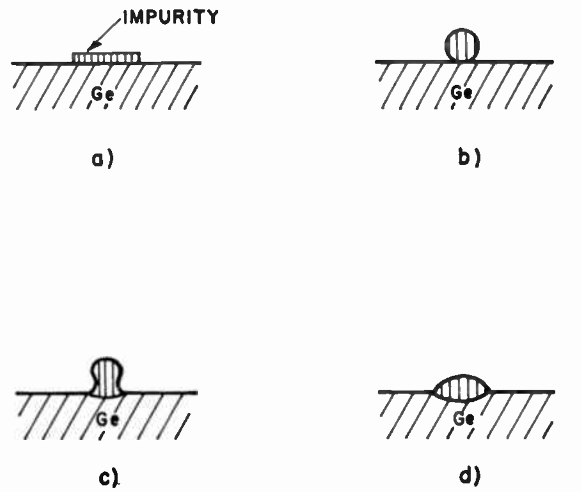

Fig. 2—Formation of an alloy junction in 4 subsequent steps.

The limit of the alloying depth is dependent on the solidus curve in the germanium-impurity phase diagram which is shown for lead-germanium in Fig. 3. Although the conditions are somewhat different for the tertiary lead-antimony-germanium system, which occurs in the n-p-n alloy transistor, Fig. 3 is an acceptable approximation due to the low antimony content in the impurity alloy. The penetration depth limit is closely related to the distance between the temperature axis and the

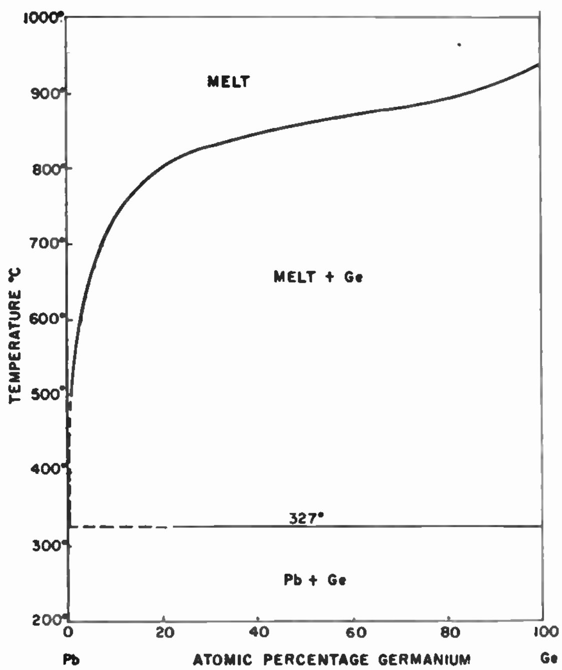

Fig. 3—Phase diagram of the lead-germanium system.

liquidus curve at the processing temperature. Due to the steepness of the liquidus line up to about 700 degrees C. the depth varies little compared with the region above 800 degrees C. Therefore the processing temperature is relatively uncritical below 700 degrees C. as was verified experimentally.

Electrical Characteristics

Electrical characteristics have been taken on over a hundred experimental n-p-n units of the type herein described; the data do not necessarily represent the ultimately attainable characteristics. These units were primarily intended for small signal, low-power applications and at low frequencies. The discussion and data are presented with emphasis on the base input (common emitter) connection which has found extensive application in apparatus. In this circuit the similarity between electron tube and junction transistor facilitates the understanding and design of the allied circuitry.

The characteristics of a transistor can be presented in several different ways, each of which has its merits. A common representation consists of the resistance values in the equivalent T-circuit as shown in Fig. 4, which describes the transistor at low frequencies, and with small signals.

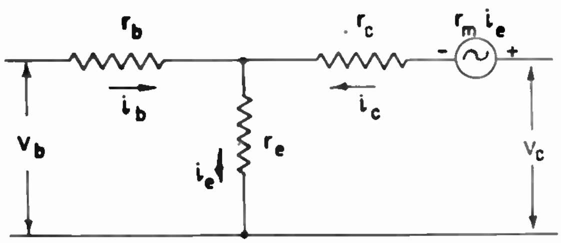

Fig. 4—Equivalent *T* circuit of a n-p-n junction transistor in the base input (emitter common) circuit.

At higher frequencies, capacitances have to be introduced and the evaluation becomes more complicated. The derivation of the various transistor characteristics from the resistance values is described in the literature.[4] The ranges of resistances which can be achieved for n-p-n alloy junction transistors, when made by variations of the procedures described in this paper, and operated at 2-ma emitter current, are of the order of

$$r_b = 100 \text{ ohms to } 2500 \text{ ohms}$$
$$r_e = 2 \text{ ohms to } 20 \text{ ohms}$$
$$r_c = 100{,}000 \text{ ohms to } 10 \text{ megohms}$$
$$r_m = 100{,}000 \text{ ohms to } 10 \text{ megohms.}$$

The r_b is strongly dependent on the germanium resistivity and can be decreased by using low resistivity germanium. The r_c is a measure of the quality of the collector junction and is greatly affected by the etching process. r_e is to some extent determined by the forward characteristics of the emitter junction. Finally, r_m is to a first approximation proportional to the product of r_c and current gain "alpha" and therefore is always lower than r_c in this type of junction transistor.

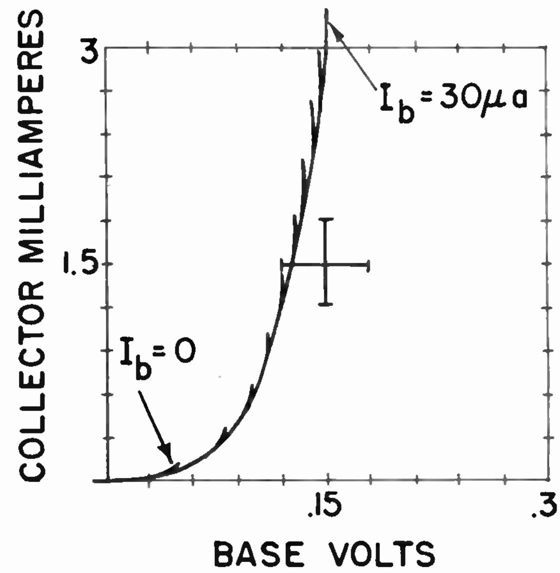

Fig. 5—Transfer characteristics of a typical low-power n-p-n alloy transistor (base current I_b in 10 equal steps from 0 to 30 ma).

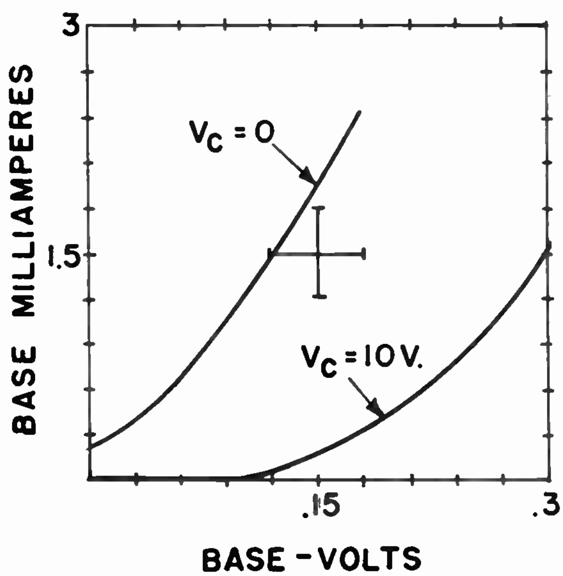

Fig. 6—Input characteristics of a typical low-power n-p-n alloy junction transistor (collector potential V_c equals 0 and 10 v).

The properties of a transistor may also be described by static characteristics similar to the well known electron tube presentation. Due to the finite input impedance of the transistor it is not sufficient to give only the output characteristics with the input potential as a parameter. An adequate picture of the transistor behavior can be obtained from a set of four curve families as are shown for a typical unit in Figs. 5 to 8.

[4] R. L. Wallace and W. J. Pietenpol, "Some circuit properties and applications of n-p-n transistors," Proc. I.R.E., vol. 39, pp. 753–767; July, 1951.

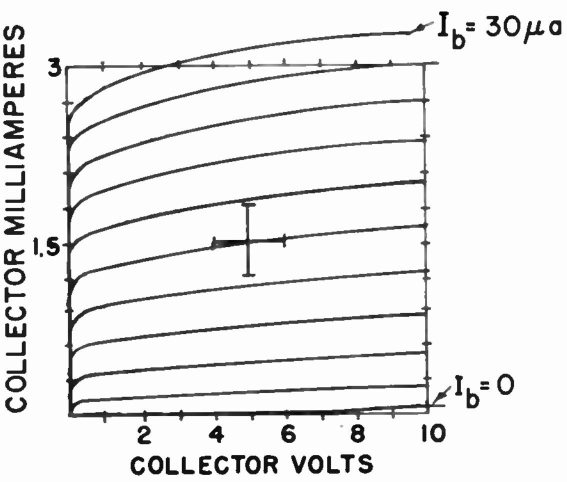

Fig. 7—Output characteristics of a typical low-power n-p-n alloy junction transistor (base current I_b in 10 equal steps from 0 to 30 μamp).

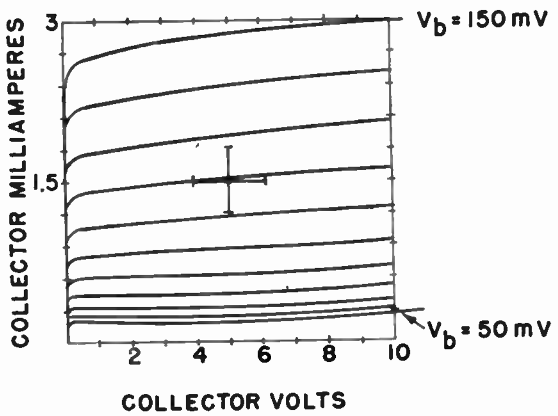

Fig. 8—Output characteristics of a typical low-power n-p-n alloy junction transistor (base potentials in 10 equal steps from 50 to 150 mv).

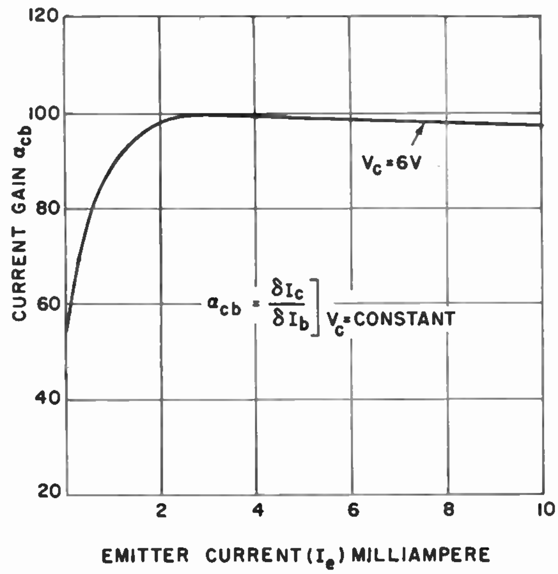

Fig. 9—Variation of the collector-base current gain α_{cb} with emitter current for a typical n-p-n transistor.

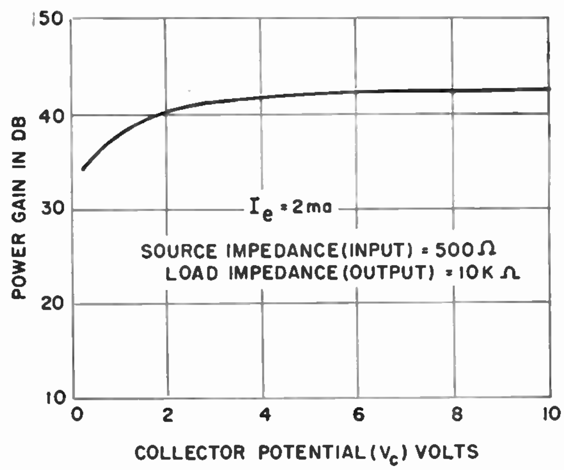

Fig. 10—Variation of power gain with collector potential for a typical n-p-n alloy junction transistor.

The static characteristics suffice, in principle, for the analysis of amplifier operation by applying suitable load lines to the curve families. In practice, however, small signal evaluation requires more accurate data than can be derived from static curves taken with a curve tracer.

The most explicit way of representing the transistor characteristics consists in the actual measurements of the important characteristics such as power gain, current gain, noise factor etc. under various bias and impedance conditions and at different frequencies. A full description of a transistor would require a large number of curves, but by suitably choosing the test conditions it is possible to cover the most important application cases. In Figs. 9 to 14, a set of curves describing the important parameters of a typical transistor are reproduced. Except for the frequency dependence data the same unit was used for these data.

The current gain in Fig. 9 is observed to be essentially constant from 2 to 10 ma, which range corresponds to a current density of several amp per cm². Similarly, the variation of the power gain with collector potential is negligible between 2 and 10 v as shown in Fig. 10. The source impedance of 500 ohms and the load impedance of 10,000 ohms are chosen to be in the vicinity of the average matching impedances for maximum power gain at an emitter current I_e of 2 ma and a collector potential V_c of 6 v. The operating currents and potentials are of arbitrary choice but lie within the most probable application range.

The noise factor results in Figs. 11 and 12 show that, in general, an increase in potential or current raises the noise, and a minimum noise factor is reached at about 1 v collector potential and 1 ma emitter current.

In the audio range, the noise factor is inversely proportional to the frequency, so that the 1,000 cycle value is readily interpreted. The 560 ohms source impedance corresponds approximately to the matching impedance for maximum power gain as pointed out above.

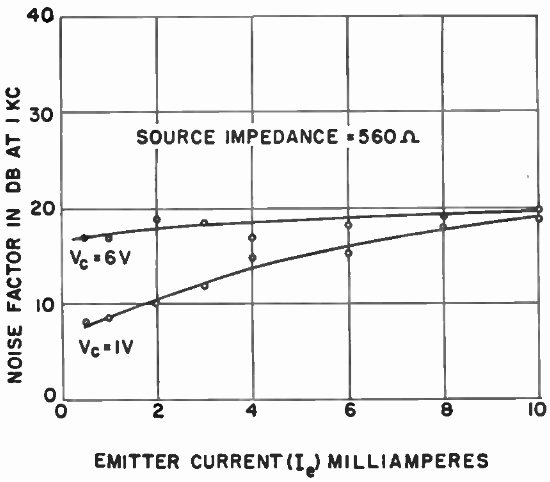

Fig. 11—Variation of noise factor with emitter current for a typical n-p-n alloy junction transistor.

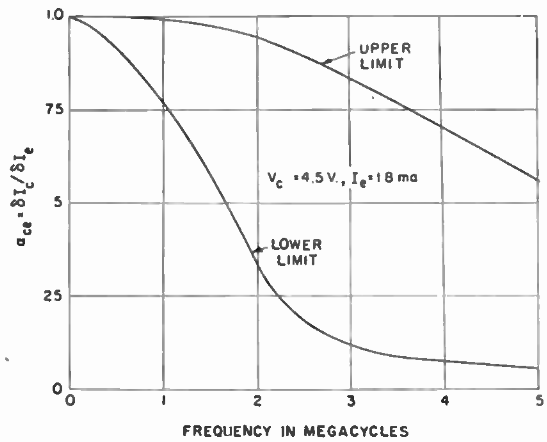

Fig. 13—The variation with frequency of collector-to-emitter current gain α_{ce}, for a lot of 100 n-p-n alloy junction transistors; all units fall between the two curves shown.

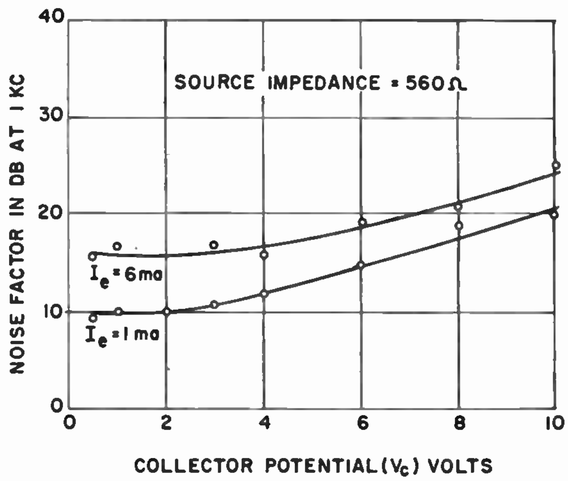

Fig. 12—Variation of noise factor with collector potential for a typical n-p-n alloy junction transistor.

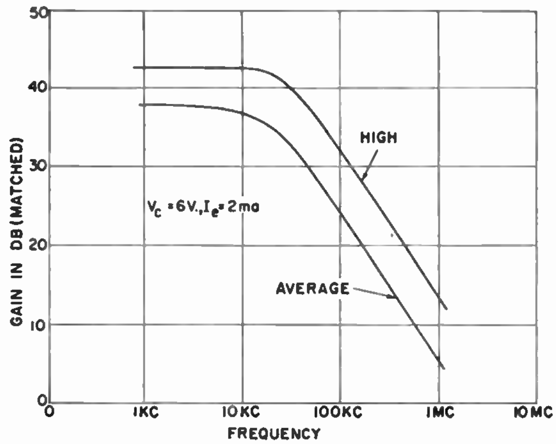

Fig. 14—Variation of power gain with frequency for typical n-p-n alloy junction transistors. A resistive input and conjugate-matched output were used.

Although the units here described were intended only for audio-frequency applications, the performance at higher frequencies is of interest. One measure of the behavior of a transistor at higher frequencies is the current amplification factor, as pointed out in the general description.

In Fig. 13 the limits represent the results on early experimental units and it can be seen that the spread is considerable at the hf end. The cut-off frequencies are between 1.2 and 4 mc.

A direct gain measurement under conditions with a resistive input and conjugate-matched output gives a more useful picture of the hf behavior as shown in Fig. 14. Presumably if a conjugate match adjustment had been available for the input, the gains would have been higher.

The average and the high power gain versus frequency curves up to above 1 mc show that useful gains are attained at intermediate frequency (455 kc), and selected units give significant gain in the broadcast band (500 kc to 1.5 mc).

A statistical evaluation of an experimental lot of 100 transistors is presented in Fig. 15 to 17 (following page). These units were made under similar conditions and constitute all the units in this test, with the exception of mechanically damaged transistors and 21 units which were eliminated due to collector leakage currents in excess of 100 μamp at 6 v collector potential and zero emitter current.

The power gain peak in Fig. 15 is very pronounced at 42 db, and more than 50 per cent of the units are within the limits of 42 ± 2 db, although the average of all transistors lies at 38.3 db.

The current gain, α_{cb} in Fig. 16, shows a peak at about 70 and more than 50 per cent of the units are within the limits 70 ± 30. Translated into emitter input current gain α_{ce} the peak is at 0.985 and the limits for more than 50 per cent of the units are 0.985 ± 0.01. The averages are, for α_{cb} at 108 and for α_{ce} at about 0.99.

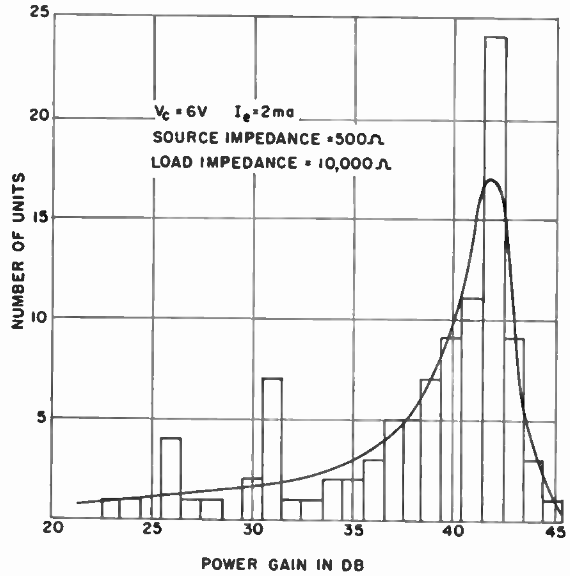

Fig. 15—Distribution of power gain for a typical lot of 100 n-p-n alloy transistors.

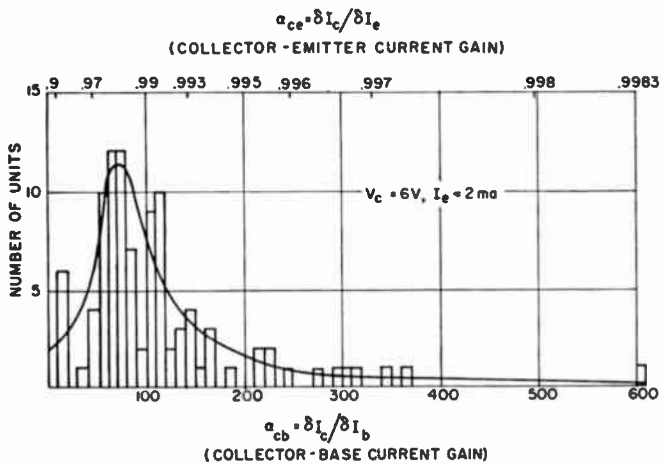

Fig. 16—Distribution of α_{cb} (collector-to-base current gain) and of α_{ce} (collector-to-emitter current gain) for a typical lot of 100 n-p-n alloy transistors.

Finally the noise factor distribution in Fig. 17 shows a peak at 9 db and more than 50 per cent of the units lie within 9±5 db with the average being 17.8 db.

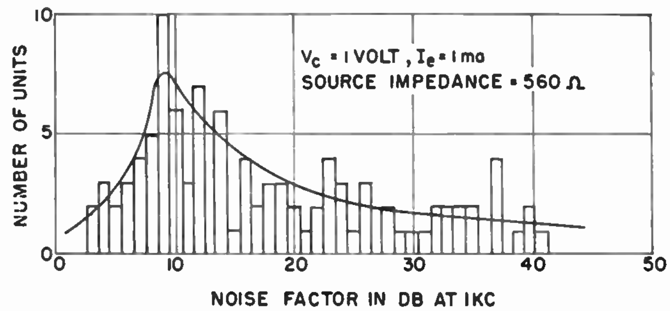

Fig. 17—Distribution of noise factor for a typical lot of 100 n-p-n alloy transistors.

Conclusions

The characteristics measured on the above described n-p-n alloy junction transistor are in general superior to those given for the p-n-p alloy junction transistor previously reported.[3] The percentage of high power gain and low noise factor units is much larger and the collector-to-base current gains are higher. Also of significance is a practically constant current gain as the collector current is increased, which was not exhibited by the p-n-p version. There are indications of improved hf performance, although the theoretical factor was not attained, which is probably due to other frequency limiting parameters. The development of an n-p-n counterpart to the previously described p-n-p alloy junction transistor, with very similar electrical characteristics, allows the practical design of circuits making use of the symmetrical properties of transistors.[1]

Capacity and Conductivity of Body Tissues at Ultrahigh Frequencies*

HERMAN P. SCHWAN†, MEMBER, IRE AND KAM LI†, STUDENT, IRE

Summary—**Dielectric constant and specific resistance are reported for a variety of body tissues throughout the frequency range from 200 to 1,000 mc. The results are analyzed and explained by the cellular structure of tissue, the electrical properties of tissue electrolytes, and tissue protein content. Other results specify the temperature dependence of the electrical constants of tissue material. The temperature coefficients vary with frequency and are in agreement with theoretical expectation. A short description of measuring technique and of tissue sample thermostat is given.**

Introduction

It has been stated previously[1,2,3] that for various reasons, uhf-radiation diathermy may be most effective when operating in the frequency range around 500 mc. In discussions of the frequency dependence of the depth of penetration of uhf-radiation[1] and of the relative development of heat in subcutaneous fat, as compared to that in muscle,[2,3] it was assumed that the electrical properties of muscle and other tissues with high water content are similar to those of blood. This assumption was based on an analytical argument and necessary since only blood measurements had been conducted in the frequency range from 100 to 1,000 mc.[4,5] It is intended to present in this paper:

1. Data of the electrical properties of various tissues in order to close the gap which exists between results which have been obtained by other investigators either below 100 mc,[6] or above 1,000 mc.[7,8,9] We further want to check the validity of the assumption concerning the similarity of the electrical properties of blood and tissues with high water content.

2. Temperature coefficients of the electrical properties of tissues in the frequency range mentioned above, to permit application of the measured data to other temperature levels of interest.

3. Theoretical analysis of the frequency dependence of electrical properties of tissue in terms of their structure and molecular content.

Measuring Technique

The measurements were carried out with a double wire system operating on a resonant principle as previously described.[1,10] The use of an "open wire" system combines the advantages of low cost of construction with the possibility of keeping the biological sample under constant observation and simplicity of temperature control. The use of the resonant technique avoids disadvantages, which may be extremely disturbing with open systems such as oscillations of the system against third conductors (ground) and sensitivity against movement of personnel operating the transmission line. Furthermore, it reduces undesirable effects caused by harmonics. The biological sample (thickness d) surrounds one small section of the line and is loaded with a $\lambda/4$ section to provide infinite load to its terminals. The input impedance of the sample may be related to standing wave ratio $W = V\,(\max)/V(\min)$, and displacement of the wave pattern l, which occurs when the sample holder is loaded. Both quantities, W and l, are determined with the measuring line in front of the sample holder. The input impedance, as observed by the measuring line, is furthermore related to the dielectric properties of the material in the sample holder. By combination, we can eliminate the input impedance value and express the electrical constants of the material in the sample holder in terms of W and l as follows:[11]

$$\epsilon = \frac{\lambda}{2\pi d}\tan\frac{2\pi}{\lambda}(l+d)\,\frac{W^2-1}{W^2+\tan^2\frac{2\pi}{\lambda}(l+d)}$$

$$\rho = 120\pi d\,\frac{1}{W}\,\frac{W^2+\tan^2\frac{2\pi}{\lambda}(l+d)}{1+\tan^2\frac{2\pi}{\lambda}(l+d)} \qquad (1)$$

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† Electromedical Labs., Dept. of Physical Medicine, Graduate School of Medicine, and Moore School of Elec. Eng., University of Pennsylvania, Philadelphia, Pa.

[1] H. P. Schwan and E. L. Carstensen, "Application of electric and acoustic impedance measuring techniques to problems in diathermy," *Transactions AIEE;* 1953, and *Com. and Elec. AIEE*, p. 106; May, 1953.

[2] H. P. Schwan, E. L. Carstensen, and K. Li, "Comparative evaluation of ultrasonics and ultrahigh frequency diathermy in medicine," *Arch. of Phys. Med.* (In press).

[3] H. P. Schwan, E. L. Carstensen, and K. Li, "Heating of fat-muscle layers by electromagnetic and ultrasonic diathermy," *Transactions AIEE;* 1953, and *Com. and Elec. AIEE*, p. 483; Sept. 1953.

[4] B. Rajewsky, and H. P. Schwan, "Die Dielektrizitaetskonstante und Leitfaehigkeit des Blutes bei ultrahohen Frequenzen," *Naturwissenschaften*, vol. 35, p. 315; 1948.

[5] H. P. Schwan, "Electrical properties of blood at ultrahigh frequencies, *Am. Jour. Phys. Med.*, vol. 32, p. 144; 1953.

[6] K. Osswald, "Hochfrequenzleitfaehigkeit und dielektrizitaetskonstante von biologischen Geweben und Fluessigkeiten," *Hochfrequenztechnik und Elektroakustik*, vol. 49, p. 40; 1937.

[7] J. F. Herrick, D. G. Jelatis, and G. M. Lee, "Dielectric properties of tissues important in microwave diathermy," *Federation Proc.*, vol. 9, p. 60; 1950, and personal communication.

[8] T. S. England, "Dielectric properties of the human body for wavelengths in the 1–10 cm. range," *Nature*, vol. 166, p. 480; 1950.

[9] H. F. Cook, "A comparison of the dielectric behaviour of pure water and human blood at microwave frequencies," *Brit. Jour. Appl. Phys.*, vol. 3, p. 249; 1952.

[10] H. P. Schwan, "Messung von Elektrischen Materialkonstanten und komplexen Widerstaenden, vor allem biologischer Substanzen," *ZS. Naturforschung*, vol. 8b, p. 3; 1953.

[11] H. P. Schwan, "Auswerteverfahren zur Bestimmung der elektrischen und magnetischen Stoffkonstanten im Dezimeterwellengebiet," *Annalen d. Physik*, vol. VI, p. 287; 1950.

(ϵ dielectric constant relative to air, ρ specific resistance in Ohm cm). The formulas are good approximations for small sample thickness values[12] and a discussion of higher terms in a series development of an accurate solution of the problem has convinced us that they are sufficient for the present purpose. Details concerning derivation, as well as errors involved, elimination of the effect of the sample holder on the field, and a complete discussion of the errors involved with this technique will be given elsewhere.[13]

The thermostat which was used for the variation of the sample temperature is shown in Fig. 1. The tissue material is introduced in thin slices, of 1 to 2 mm thickness, between the two center plates of polystyrene.

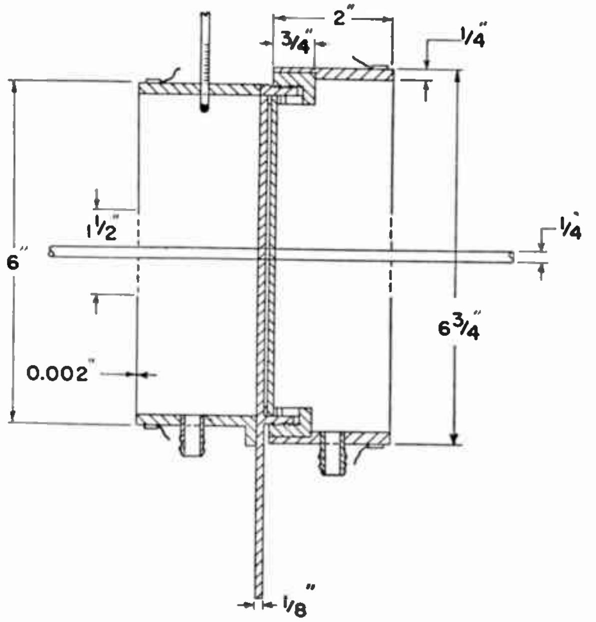


Fig. 1—Side view of sample holder with thermostat.

Slight pressure is applied by the plates to assure that the tissue sample thickness is identical with the thickness of the spacer rings and center pieces which keep the plates at a defined distance. The picture presents a side view with the two conductors of the double wire system appearing as one. Polystyrene rings are attached to the sample holder at a distance sufficiently great to avoid any effect on the field distribution around the wires. At the ends of the rings thin sheets of polystyrene (0.05 mm thick) are fastened with rubber bands. They have a center hole of about $1\frac{1}{2}$ inches and do not influence the field. Air enters through inlets in the bottom of the arrangement, and escapes through the center holes in the plastic sheets, thereby reducing the possibility that the high thermal conductivity of the conductors may cause a substantial decrease in temperature in the immediate vicinity of the center. The temperature of the air is at present regulated with a simple condenser arrangement, utilizing compressed air, which is available in the laboratory, and hot water flowing around the coils of the condenser. The temperature is regulated by variation in air and water flow or by variation of the water-temperature circulating through the condenser. The arrangement has the great advantage that it combines effective performance with simplicity of construction. It has no measurable effect on the electrical field, which is essential in avoiding complications in the mathematical evaluation of the measurements.[14]

The curves in Fig. 2 are self-explanatory and show that temperature stability is reached within one half to one hour. The temperature through the sample agrees within about 0.5° C. with the temperature of the air, as measured with a thermometer. Another test was performed by measuring the electrical properties of electrolytic solution whose electrical resistivity at low frequencies was found to be 154 ohm cm at 27° C. The temperature coefficient of this solution is known from tables and permits calculation of its low frequency resistivity at 38° C., yielding a value of 131 ohm cm. Application of polar theory[15] makes it possible to determine analytically the total frequency dependence of the resistivity of

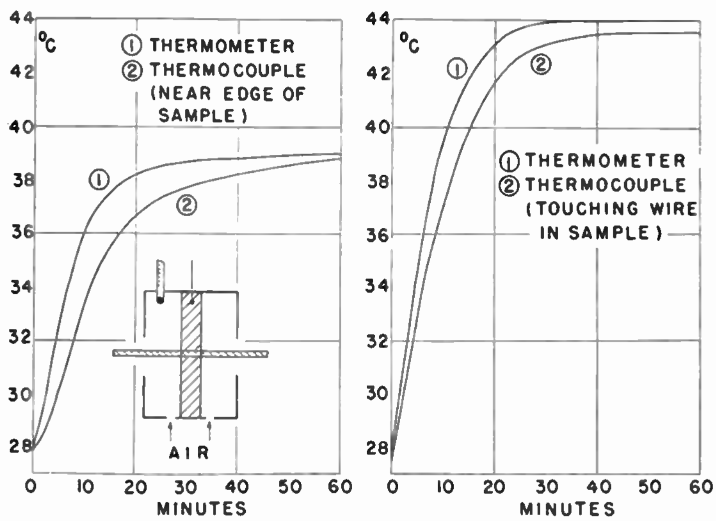


Fig. 2—Temperature of thermostat and sample as function of time. These are two different experiments carried out with different air temperature.

the saline solution. The characteristic frequency values for water necessary in this calculation are taken from Conner and Smyth,[16] and supported by evaluation of water measurements as carried out by Herrick, Jelatis, and Lee[7] and us.[10] The result is given in Fig. 3 and fits with the experimental results within a few per cent. The dielectric constant is frequency independent according to Debye's theory up to about 1,000 mc. The difference

[12] Sample thickness values of 1 and 2 mm have been used.

[13] H. P. Schwan, and K. Li, "Measurements of materials with high dielectric constant and conductivity at ultrahigh frequencies," conference paper presented before AIEE, General Summer Meeting, Atlantic City, N. J.; June, 1953.

[14] H. P. Schwan, "Der Einfluss von Halterungen am Ende von Lecherleitungen," *Annalen d. Physik*, vol. VI, p. 268; 1950.

[15] P. Debye, "Polar Molecules," Chemical Catalog Co., Inc., New York, N. Y.; 1929.

[16] W. P. Conner, and C. P. Smyth, "The dielectric dispersion and absorption of water and some organic liquids," *Jour. Am. Chem. Soc.*, vol. 65, p. 382; 1943.

in dielectric constant between 27° C. and 38° C. is in our case 5 in agreement with earlier observations on distilled water.[16,17] The deviation of the experimental points from the theoretical curves is explained by an error estimate according to which dielectric constants are accurate within about 2 per cent and resistance value accurate within 5 per cent.

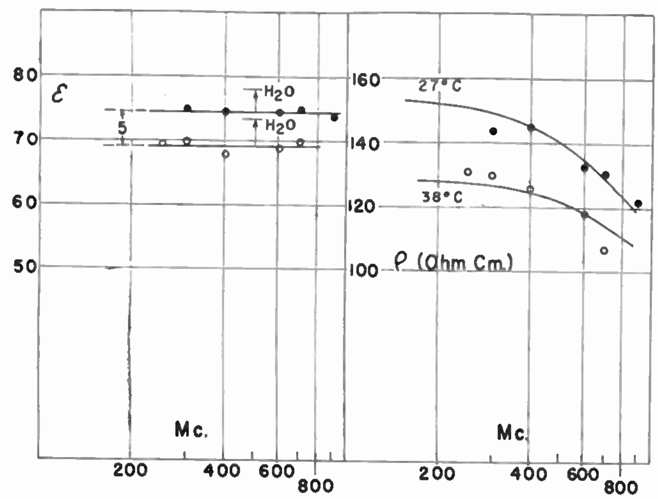


Fig. 3—Dielectric constant and specific resistance of NaCl solution at 27° and 38° C.

Results

The Tables 1 and 2 show dielectric constant and specific resistance of muscle tissue, heart muscle, kidney, liver, lung, fat, and blood, as function of frequency. Human autopsy material of normal composition with regard to all the factors which determine the electrical properties at ultrahigh frequencies was used. No time effect could be noticed. The results are, therefore, characteristic for the values as given in the live body. This is to be expected, since the factors which determine the electrical properties at ultrahigh frequencies are not subject to rapid change after death. The biological material was cut in pieces of a size suitable for the test vessel and measured in the majority of cases at room temperature, i.e. at 27° C.±1° C. Beef blood was measured with a small amount of heparin added to avoid coagulation. Physiological saline solution (0.9% NaCl) was measured on various occasions and the results are included for comparative purposes. Other measurements with saline solutions of different salt concentration and measurements with distilled water were also carried out.

Also included in the tables are values determined by Herrick, Jelatis, and Lee[7] at 1,000 mc. Their measurements were carried out at 37° C. They are corrected to a temperature of 27° C., utilizing the temperature coefficients determined by us to permit comparison. These values agree very well with those obtained by us at 900 mc. In general it can be said that the range of variation is surprisingly small for biological material with high water content. This again may be related to the fact that the factors of importance for the uhf-impedance of biological material (H_2O-salt-nonaqueous matter) are not subject to excessive variation. It is noted that liver covers a wider range of values which we may relate to the fact that its glycogen and fat content varies somewhat. Lung tissue is very much affected by its air content, which lowers ε and increases ρ as compared to other tissues. The sample included in the Tables was in a rather deflated condition, and may, therefore, be con-

[17] J. Wyman, Jr., "The dielectric constant of mixtures of ethyl alcohol and water from −5 to 40°," *Jour. Am. Chem. Soc.*, vol. 53, p. 3292; 1931.

TABLE I

Dielectric Constant of Various Tissues as Function of Frequency at 27° C.

ε	Samples	200	300	400	600	700	900	1000 Mc. (Herrick)
Muscle	2	56	55–57	54–56	55–56	55–56	53–55	54–57
Heart M.	3	59–63	55–62	54–58	54–58	53–58	53–57	
Liver	4	50–56	48–56	46–53	46–53	46–54	44–52	50–51
Kidney	2	62	57–60	55–57	54–56	53–56	53–56	
Lung	1	35	36	36	36	35	35	
Blood	1	67	63	64	62	62	63	63–67
0.9% NaCl	2	75	77	74	79	77	78	77
Fat	3	4.5–7.5		4–7			3.2–6	

TABLE II

Specific Resistance of Various Tissues as Function of Frequency at 27° C.

ρ	Samples	200	300	400	600	700	900	1000 Mc. (Herrick)
Muscle	2	110–120	105–110	100–105	94–100	87–93	81–84	79–83
Heart M.	3	110–130	105–120	100–115	95–115	92–110	83–100	
Liver	4	125–170	120–155	120–150	110–140	100–130	92–120	104–110
Kidney	2	104	100–102	98	90–94	89–90	81–82	
Lung	1	190	170	163	156	152	137	
Blood	1	96	90	91	92	85	80	70–78
0.9% NaCl	2	58	59	58	56	54	56	54
Fat	3	1500–5000		1300–4000			1100–3500	

sidered as a sample with high ϵ and low ρ as compared to actual in situ conditions. Another material whose electrical data vary considerably is fat. This is probably because the water content of fatty tissue varies extremely. The values of all tissues with high water content are around 50 (dielectric constant) and 100 ohm cm (specific resistance). Fat, a material with low water content, has a higher resistivity and lower dielectric constant.

Fig. 4 shows in greater detail the frequency dependence of muscle and liver. The curves are shown to demonstrate the typical frequency behavior found in tissue with high water content. It is seen that the dielectric constant is constant at high frequencies and often increases as the frequency decreases below 300 mc. The resistivity curve indicates the superposition of two major frequency variations. One occurs at frequencies far in excess of 300 mc and one occurs predominantly far below 300 mc.

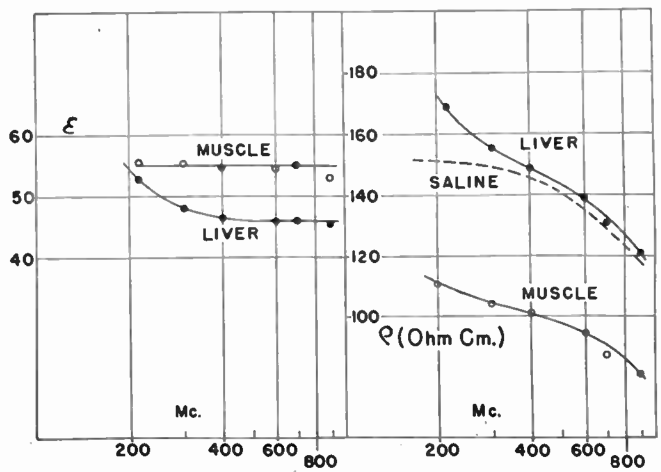


Fig. 4—Dielectric constant and specific resistance of muscle and liver tissue as function of frequency.

Analysis of Results

The structure of tissues with high water content is determined by cell envelopes which have rather high capacity and resistance and are extremely thin. Inside and surrounding these cell membranes are salt solutions of an ionic strength comparable to physiological saline solution (0.9% NaCl). These solutions contain protein molecules, i.e. macro-molecules of considerable size and high molecular weight. The shape of these proteins may be approximated by ellipsoids of revolution with an axis ratio varying from 1 to 10.

The influence of the cell membranes on the electrical impedance has been investigated in a great number of articles in the past (see for example[18,19,20]). A somewhat over-simplified model circuit characterizes their influence (Fig. 5). In this circuit the membranes are represented by capacitances, the interior of the cells by a resistance in series with the membrane capacitances, and the exterior fluid by the resistance R_0 in parallel with a capacitance C_∞. Dielectric constant and resistance, defined in an equivalent parallel RC-combination follow the laws given in Fig. 5. The subscripts 0 and ∞ indicate values of dielectric constant and conductivity $\kappa = 1/\rho$ as determined at extremely low and high frequencies. T is a time constant, essentially identical with the product RC of the circuit, and determines the angular frequency $\omega_0 = 1/T$ where the change with frequency is most pronounced. Actually, it has been shown that either a series of time constants, varying with cell size and shape, or a more complicated impedance for the cell membrane exist. As frequency increases, the capacity of the interior and exterior fluid cannot be neglected. But these are refinements which do not affect the basic phenomena of a decrease of both capacity and resistance with increasing frequency to a constant level. The range of major change has been found to exist in biological material around 10 kc to 10 mc, while near 100 mc, constant values are approached. The change of both electrical data which occurs as the frequency decreases below 300 mc is, therefore, due to the inhomogeneous structure of the tissues (cell membrane capacities).

$$\varepsilon = \varepsilon_\infty + \frac{\varepsilon_0 - \varepsilon_\infty}{1+\omega^2 T^2} \quad ; \; \kappa = \frac{1}{\rho} = \kappa_0 + (\kappa_\infty - \kappa_0)\frac{\omega^2 T^2}{1+\omega^2 T^2}$$

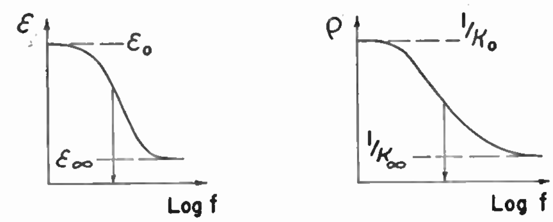


Fig. 5—Simplified equivalent circuit and equations characterizing frequency dependence of tissue and blood due to cellular structure.

As the frequency increases more and more, another effect appears, which is related to the electrical polarity of water molecules. As changes in field direction become more rapid, inertia eventually makes it impossible for the dipolar molecules to follow the alterations of the electrical field and a consequent decrease in electrical polarization occurs. Here again the relationship (1) applies. However, the parameters have different values.[21] Both "dispersion" ranges are separated by a more or less

[18] H. Fricke, "The electric conductivity and capacity of disperse systems," *Physics*, vol. 1, p. 106; 1931.

[19] K. S. Cole, and H. J. Curtis, "Medical Physics," The Year Book Publishers, Inc., Chicago, Ill., p. 344; 1944.

[20] B. Rajewsky, "Ergebnisse biophysikalischer Forschung," vol. I, Georg Thieme, Leipzig; 1938.

[21] ϵ_∞ of the "structural dispersion" is identical with ϵ_0 of the polar dispersion. The "characteristic wavelength" (sprungwellenlaenge) of the polar dispersion is near 2 cm while it varies between 100 m and 10,000 m in the case of structural dispersion of tissue with high water content and blood.

pronounced frequency region where the electrical data are relatively frequency independent. This flat level is very obvious in the case of the dielectric constant since it follows from the equations (1) that the dielectric constant begins to decrease at first at frequencies above 1,000 mc.[22] The resistance on the other hand decreases much more rapidly in agreement with the equations for the polar dispersion.[22] An electrolytic solution with a resistivity similar to that of tissue has been calculated for comparative purposes and the result is indicated by the dashed line in Fig. 4, proving that the resistance change of tissues above 300 mc is due to its water content.

A third effect must be discussed, aside from the effect of structural components (cell membranes) and polarity of water. Protein molecules contribute about 20 gm per 100 cc volume in tissue with high water content. The partial volume of protein molecules is about 0.75. The amount of water which is fixed to protein and can be considered insoluble for salts may be assumed in the neighborhood of 0.3 gm per gram protein.[9,23,24,25] The volume which does not participate in electrical conduction is, therefore, in the vicinity of 20 cc per 100 cc material. We can assume that the protein and the bound water establish particles of ellipsoidal shape.[26] Considering that electrical conductivity and dielectric constant of the hydrated protein are much smaller than those of the surrounding saline solution, Fricke's equation[26,9]

$$K_t = K_s \frac{1-p}{1+fp} \tag{2}$$

can be applied. Here, K may be either conductivity or dielectric constant, p is the relative volume occupied by the hydrated protein and the indices t, s indicate total solution and solvent. f is a factor which depends on the shape of the protein particles. It is 0.5 for spherical form and increases to a value of 1 for elongated particles. From this, it follows that the presence of protein molecules reduces dielectric constant and conductivity of the surrounding saline solution 27 to 33 per cent. This, combined with the fact that the dielectric constant of saline is 77 at 27° C. leads to a prediction of 52 to 56 for the dielectric constant. This prediction applies, of course, only to the tissues with high water content in the frequency range where neither structural nor dipolar dispersion affect the data, i.e. above 300 and below 1,000 mc. The values for heart, muscle, and kidney fall in predicted range. The liver values extend down to 44. This may be due to the relatively large amount of glycogen and fat which has not been considered in our argument and which causes a further reduction. Lung is appreciably lower due to its high air content in spite of the fact that it was measured in a state of collapse and consequently deflated. The protein content for blood is lower, about 15 g per 100 cc and the majority of its proteins (hemoglobin) nearly spherical. Hence, a dielectric constant of about 60 is anticipated. This is in agreement with the result and similar investigations carried out by Cook[9] and others.[7] A similar calculation permits determination of the resistance of the fluid surrounding the protein molecules. It is found to be near 70 ohm cm and about 20 per cent higher than the resistance of 0.9 per cent saline solution. This difference is due to the fact that potassium replaces in the intracellular fluid a large part of the sodium ions with different ion mobility.

Temperature Studies

It is desirable to obtain data at different temperatures, to permit a transfer of the results to other temperatures. Measurements at different temperature levels were, therefore, conducted. The results obtained apply to fatty tissue samples, kidney, heart muscle, and liver tissue. Fig. 6 shows a typical result obtained with kidney tissue. The temperature coefficient of the resistance varies with the frequency. It is always negative and comparable to that of saline solution. This is in agreement with the analysis which has been advanced above.

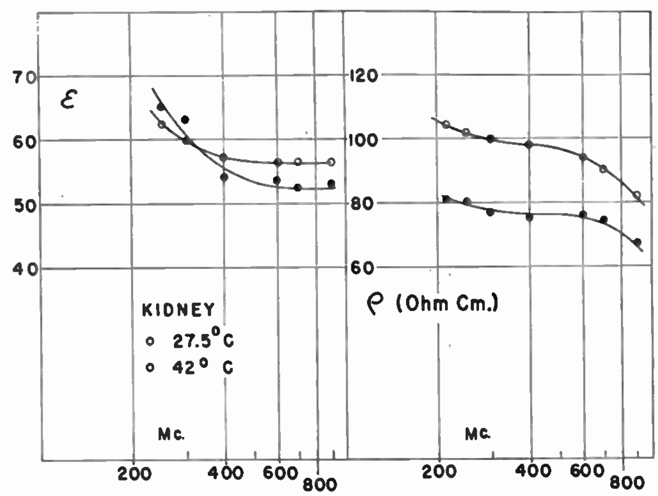


Fig. 6—Dielectric constant and specific resistance of kidney tissue as function of frequency and temperature.

The temperature coefficient of the capacitance is positive at low frequencies, becomes zero, and finally negative as the frequency increases. The explanation of the data at the high frequencies is based on the fact that the temperature coefficient of the dielectric constant of

[22] The following data hold for salt solutions and determine its polar dispersion: ϵ_0 about 76 at room temperature (Schwan, "Der einfluss von halterungen an ende von lecherleitungen," loc. cit.) ϵ_∞ about 4 to 5 (Cook, "A comparison of the dielectric behaviour of pure water and human blood at microwave frequencies," loc. cit.). The characteristic wavelength varies approximately between 1.8 cm at 27° C. and 1.5 cm at 38° C., according to our measurements and data from an evaluation of results given by Herrick, Jelatis, and Lee, as well as data given by Conner and Smyth.

[23] D. L. Drabkin, "Hydration of macro sized crystals of human hemoglobin and osmotic concentration in red cells," *Jour. Biol. Chem.*, vol. 185, p. 231; 1950.

[24] G. Haggis, T. J. Buchanan, and J. B. Hasted, "Estimation of protein hydration by dielectric measurements at microwave frequencies, *Nature*, vol. 167, p. 607; 1951.

[25] J. L. Oncley, "The investigation of proteins by dielectric measurements, *Chemical Reviews*, vol. 30, p. 433; 1942.

[26] H. Fricke, "A mathematical treatment of the electric conductivity and capacity of disperse systems. *Phys. Rev.*. vol. 24, p. 575; 1924.

saline solution is negative and has the same value within the accuracy of our measurements. At lower frequencies a somewhat more complicated situation exists. It has been shown that the temperature coefficient of the capacity of blood at 1 kc and consequently the capacity of the erythrocyte membrane is practically temperature independent.[27] Similar results have been obtained by us with other tissues (unpublished material). The variation in speed with which the biological membranes are charged at different temperatures is determined only by the variation of the extra- and intra-cellular fluid resistance with the temperature. (The time constant $T=R\times C$ in the circuit Fig. 5 changes proportionally with R as the temperature varies.) This means that the total dispersion curve due to the structure of the biological material shifts to higher frequencies by a ratio f_1/f_2 which is equal to the ratio R_2/R_1. The R-ratio may be taken either from the two ρ-curves in Fig. 6 or directly from tables which give the resistivity of saline solutions as function of temperature. This ratio is about 1.3 for a change from 27° to 42° C. It is possible, therefore, to predict from one dispersion curve of ϵ others at different temperatures simply by shifting it in frequency as outlined above, and changing their ordinate by a constant value as determined by the temperature coefficient of the dielectric constant of water. The curve in Fig. 6 which is given for a temperature of 42° C. has been determined that way from the 27° C. curve. The curve fits with the experimental values within the accuracy of the determination. This may be considered as another support for the analytical arguments advanced above.

Table 3 summarizes the temperature coefficients as determined in various tissues with high water content.

TABLE III

TEMPERATURE COEFFICIENT OF DIELECTRIC CONSTANT AND SPECIFIC RESISTANCE AT VARIOUS FREQUENCIES (IN PER CENT PER DEGREE CENTIGRADE)

	Heart	Kidney	Liver	Average	Saline	
200	−1.5	−2.0	−1.8	−1.8	−1.7	
400	−1.3	−2.0	−1.8	−1.7	−1.6	$100\frac{\Delta\rho}{\rho}$/°C
900	−1.0	−1.3	−1.4	−1.2	−1.3	
200	0	+0.2	+0.2	+0.1		
400	−0.2	−0.2	−0.2	−0.2	−0.4	$100\frac{\Delta\epsilon}{\epsilon}$/°C
900	−0.2	−0.4	−0.4	−0.3		

The values are compared with the temperature coefficient of saline solution and fit well into the picture outlined above. The positive temperature coefficient of the dielectric constant is never larger than 0.2. The temperature coefficient of the resistivity is always negative and in the neighborhood of 1.7 per cent per degree C. for frequencies lower than 400 mc. At higher frequencies it decreases in agreement with the theoretical prediction. This is a result of the fact that the temperature coefficient of saline solution decreases when polar losses add substantially to the ionic conductivity. The values given for saline solution are theoretically calculated from the dispersion equation assuming a low frequency conductivity of about 80 ohm cm, which is near the value indicated for cellular fluid as outlined above.

The temperature coefficient of fat cannot be explained on the basis of the model proposed for the tissue with high water content. The coefficient for the capacitance decreases slightly as the frequency increases and varies from 1.3 per cent at 150 mc to 1.1 per cent at 900 mc. The temperature coefficient of the resistivity is rather large and negative. Its value is −4.9 per cent at 150 mc and −4.2 per cent at 900 mc.

CONCLUSIONS

1. Electrical data are presented for a number of tissues over a frequency range from 200 to 900 mc.
2. The temperature coefficient of dielectric constant and resistivity is determined for various tissues over the frequency range from 200 to 900 mc.
3. An analysis is given which explains the frequency behavior and the temperature coefficients of both dielectric constant and resistivity of water content. It is presented in terms of parameters which characterize the inhomogeneous structure of the material, the polar properties of water molecules, and the protein content.
4. The results show the similarity of the dielectric properties of all tissues with high water content and whole blood. Previously formulated opinions concerning the relative heating of fat muscle layers with radiation diathermy are, therefore, justified.

ACKNOWLEDGMENT

We are indebted to Dr. D. L. Drabkin and Dr. J. B. Marsh, of the Department of Physiological Chemistry, Medical School, University of Pennsylvania, who have carried out protein determinations of various tissue samples and have been extremely helpful in discussions concerning proteins in tissue and blood.

Furthermore, we express our appreciation to Dr. W. F. Sheldon of the Department of Pathology, School of Medicine, University of Pennsylvania, and Dr. W. Beckfield, Department of Pathology, Philadelphia General Hospital, for their preparation of the tissue samples.

[27] H. P. Schwan, "Die Temperaturabhaengigkeit der Dielektrizitaetskonstante von Blut bei Niederfrequenz," *ZS. Naturforschung.*, vol. 3b, p. 361; 1948.

Low-Noise Traveling-Wave Tubes for X-Band*

DEAN A. WATKINS†, ASSOCIATE, IRE

Summary—**The experimental results of a program of study on low-noise traveling-wave tubes for 9,000 mc are described. Tests of tubes utilizing velocity jumps for noise reduction show that a single, gradual jump upward in voltage results in the best noise reduction. The design of a tube having 11.3 db noise figure and 18 db gain at 9,000 mc is given. Curves for the variation of noise figure with magnetic field, operating voltages, and cathode temperature are presented. The experimental results obtained from measuring the noise figure of some of the tubes at different frequencies suggest an empirical modification of the simple theory.**

INTRODUCTION

THE RANGE at which radar can first detect an object is a function of the noise figure of its receiver. Because of the inverse-fourth-power law, an improvement in receiver noise figure of 3 db would result in an increase in range of 19 per cent. Present receivers employ a silicon crystal mixer and IF amplifier whose noise figure in combination is of the order of 10 to 11 db at X-band.

Because of the desirability of improving the noise figure and protecting the crystal against burnout on strong signals, the addition of a traveling-wave tube preamplifier to the receiver would be feasible if its noise figure were small enough. The objectives of the present work were to increase our understanding of shot noise phenomena in traveling-wave tubes and to build an experimental amplifier with reasonable gain and as small a noise figure as possible at X-band. The best result was a tube with 11.3 db noise figure and 18 db gain in the frequency range 8.5 to 9.6 kmc. The detailed experimental results and an empirical theory of noise in velocity-jump traveling-wave tubes appear in the following sections.

NOISE REDUCTION WITH VELOCITY JUMPS

Of all the schemes proposed for reducing noise in traveling-wave tubes, the only one which has been successful so far is the method of velocity jumps. The theory of this method, together with a description of some experimental work at 3,000 mc, has been described earlier.[1,2]

The theory follows the method used by Pierce[3] in which he assumes that the noise currents in an electron stream originate in the velocity fluctuations existing at the cathode from which the electrons are emitted. This calculation results in the prediction that the noise convection current and velocity can be represented as standing waves along the electron stream. This is shown schematically in Fig. 1. The noise convection current is shown as varying sinusoidally with distance, and the distance from one maximum (or minimum) to the next maximum (or minimum) is one-half the plasma, or space-charge, wavelength dealt with by Hahn.[4] It corresponds to twice the optimum bunching distance of small-signal klystron theory.[5] Experiment[6,7] has shown that the theory is substantially correct insofar as it predicts the space-charge wavelength and the position and amplitude of the periodic maxima, but where the theory predicts that the periodic minima will be zero, experiment shows that they are about 15 to 20 db below full shot-noise. No satisfactory theory has been advanced that accounts for this value of the minima, although various attempts have been made.[7-9]

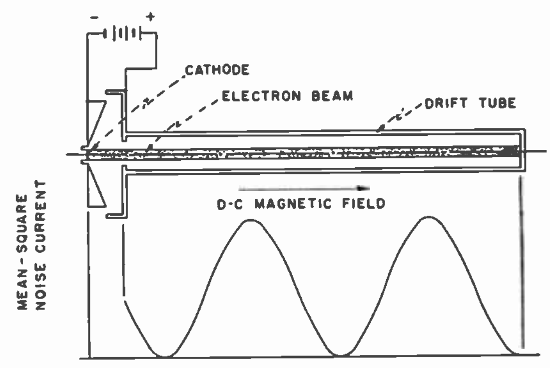


Fig. 1—The mean-square noise convection current in an electron stream drifting in an axial magnetic field.

Despite this failure of the simple theory, the method of velocity jumps is successful in improving the noise figure of traveling-wave tubes. The electrode arrangement for two different schemes is shown in Fig. 2. In the *single-jump method*, the electron-gun anode is followed by a drift space at the anode potential of such length that an ac velocity maximum occurs at the output end. Simple kinematic analysis of the gap shows that

* Decimal classification: R339.2. Original manuscript received by the Institute, March 4, 1953. This work was done at the Hughes Research and Development Laboratories, Culver City, Calif.

† Electronics Research Laboratory, Stanford University, Stanford, Calif.

[1] D. A. Watkins, "Traveling-wave tube noise figure," PROC. I.R.E, vol. 40, pp. 65–70; Jan., 1952.

[2] R. W. Peter, "Low-noise traveling-wave amplifier," *RCA Review*, vol. 13, pp. 344–368; Sept., 1952.

[3] J. R. Pierce, "Traveling-Wave Tubes," D. Van Nostrand Company, Inc., New York, N. Y., chap. 10; 1950.

[4] W. C. Hahn, "Small signal theory of velocity modulated electron beams," *GE Review*, vol. 42, pp. 258–270; June, 1939.

[5] S. Ramo, "The electronic wave theory of velocity-modulation tubes," PROC. I.R.E., vol. 27, pp. 757–763; Aug., 1939.

[6] C. C. Cutler and C. F. Quate, "Experimental verification of space-charge and transit time reduction of noise in electron beams," *Phys. Rev.*, vol. 80, pp. 875–878; Dec. 1, 1950.

[7] H. E. Rowe, "Shot noise in electron beams at microwave frequencies," Doctoral Dissertation, Mass. Inst. of Tech., Cambridge, Mass.; 1952.

[8] D. A. Watkins, "The effect of velocity distribution in a modulated electron stream," *Jour. Appl. Phys.*, vol. 23, pp. 568–573; May, 1952.

[9] J. R. Pierce, "A new method of calculating noise in electron streams," PROC. I.R.E., vol. 40, pp. 1675–1680; Dec., 1952.

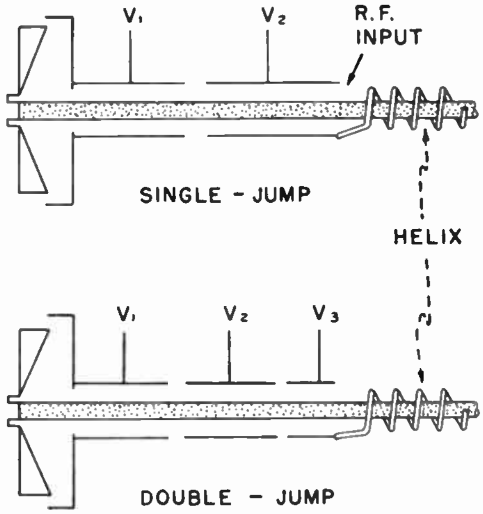


Fig. 2—Electrode configuration for velocity-jump noise reduction schemes.

the ac velocity to the right of the gap at the entrance to the high potential drift space will be reduced according to the relationship:

$$v_2^2 = \frac{V_1}{V_2} v_1^2, \tag{1}$$

where v_1 and v_2 are the ac velocities on the left-hand and right-hand sides of the gap, respectively, and V_1 and V_2 are the corresponding dc beam potentials. Since the amplitude of the convection current standing wave in the high-potential region depends upon the ac velocity modulation which produced it, its amplitude is less than the amplitude of the convection current wave in the low-potential region and the improvement in noise figure is simply V_1/V_2. According to this calculation, it should be possible to reduce the noise figure without limit simply by reducing the ratio V_1/V_2.

The second scheme employs *two velocity jumps* and is thought to work as follows. The electron-gun anode is followed by a drift space at the same potential and of such length that an ac convection current maximum occurs at its output. This is followed by a drift space at a lower potential, its length being one-fourth space-charge wavelength, and this in turn is followed by a drift space at the potential of the helix. Kinematic analysis shows that ac convection current is continuous across such a gap. The analysis shows that the noise figure improvement of such a system in terms of the ac velocity is

$$v_3^2 = \left(\frac{V_2}{V_1}\right)^{1/2} \frac{V_2}{V_3} v_1^2. \tag{2}$$

Again there is no limit set by the simple theory on the amount of improvement obtainable.

When the experimental work described here was begun, the double-jump scheme appeared to be the more advantageous in that a large amount of noise-figure improvement could be obtained without having to resort to a low anode voltage and a high helix voltage. The low anode voltage was objectionable because it required the use of a gun of high perveance. The high helix voltage was objectionable because of the well known difficulties with power supplies and insulation that it pre-

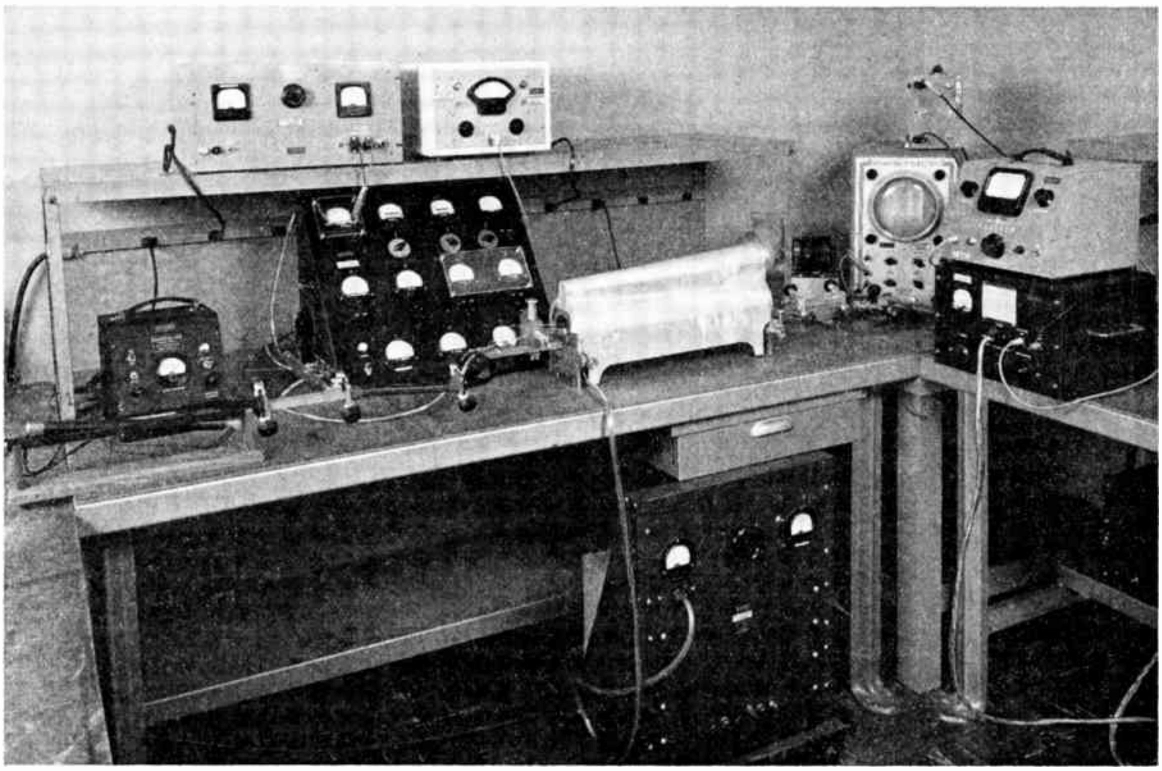


Fig. 3—Test bench for noise measurements on experimental tubes.

sents. For these reasons the double-jump arrangement was employed in the first partially successful attempt to build a low-noise tube for the X-band.

Experimental Results

All of the tubes to be described here were designed for operation from 8.5 to 9.6 kmc. The input and output matches were designed for mounting in standard waveguide (RG-52/U) and, except for one attempt with a folded-back match, they were of the conventional cylinder and antenna type. The tubes all operated in a focusing coil that provided a flux density of up to 600 gauss at its center. Most of the tubes gave the best beam transmission when their guns were even with the end of the focusing coil, where the flux density was half that at the center. Beam transmission to the collector of 99 per cent or better was considered acceptable.

The test bench arrangement for the low-noise tubes is shown in Fig. 3. A germicidal fluorescent lamp noise source was used together with an X-band radar receiver having a noise figure of 11 db. Noise powers were measured at the output of the receiver IF amplifier by means of a bolometer and a Hewlett-Packard Model 430A bridge. The gain of the tubes was measured by means of a signal source, a calibrated waveguide flap attenuator, and a crystal detector.

Double-Jump Tubes

One of the double-jump tubes (LN1) tested is shown in Fig. 4, with the constructional details shown schematically in Fig. 5. The lowest noise figure measured on this tube was 16 db at a net gain of 16 db. To compare the noise figure of the tube with the simple theory in some detail, the theoretical and experimental values were compared as a function of the voltage on the second drift space, V_3. This is shown in Fig. 6. The general shapes of the two curves are similar, but where the theory predicts a low noise figure (7 db) this was not obtained experimentally.

A second tube (LN2) was tested; this was the same design as LN1 except for the helix, which was wound with 48 turns per inch of 0.010-inch tungsten wire of an inside diameter 0.070 inch. The performance of this tube was similar to that of LN1 except that the lowest noise figure was 17 db at a gain of 11 db.

Single-Jump Tubes

After having tested several of the double-jump tubes with only moderate success, it was felt that the single-jump scheme might offer the possibility of obtaining lower noise figures because of less electrostatic lens action. At the voltage jumps in both the single-jump and double-jump tubes, there are strong electrostatic lenses. These serve to increase the dc velocity spread of the

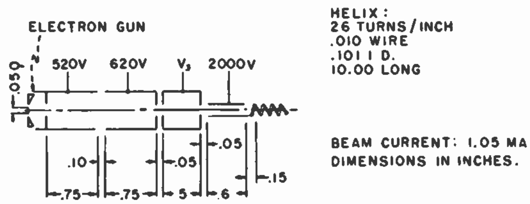


Fig. 5—Tube LN1: constructional details, important dimensions, and operating conditions.

electron stream. Since analysis shows[8,9] that velocity spread is of some importance in determining the noise in an electron stream, it was felt that one lens might be better than two. These tests were carried out on a series of single-jump tubes, the first of which (LN4) is shown schematically in Fig. 7. In this and subsequent single-jump tubes, the electrodes were shaped so as to reduce lens action by making the transition from the low-potential to the high-potential space relatively long. Analysis shows that a jump upward in voltage can have appreciable length before the noise reduction suffers by any significant amount.

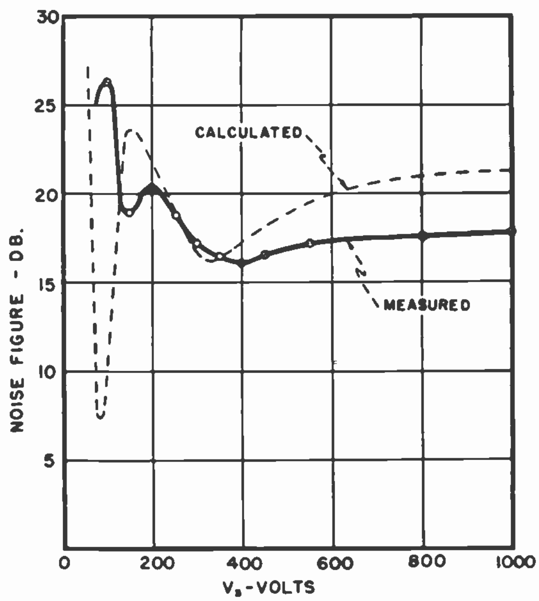


Fig. 6—Measured and theoretical noise figure as a function of the voltage on the low-voltage drift-space and the operating conditions of Fig. 5.

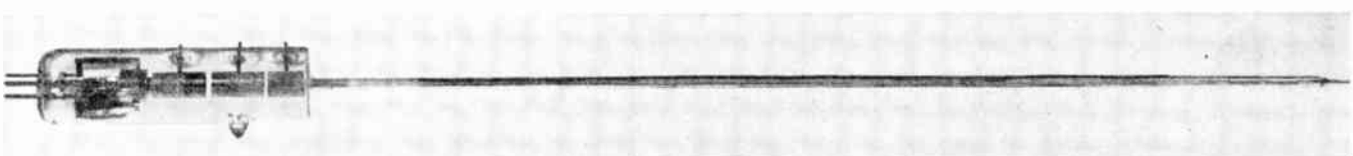


Fig. 4—Tube LN1.

The lowest noise figure obtained with this tube was 14.5 db—obtained under the conditions shown in Fig. 7. Application of the simple theory to the tube under these conditions yields a theoretical noise figure of about 14 db. This agreement between theory and experiment led to the construction of tube LN5, which differed from LN4 only in that the distance from the gun anode to the first jump was halved. The design, together with the operating voltages for lowest noise figure, is shown in Fig. 8. Since this change resulted in lowering V_2 but with all the other parameters kept the same as for the previous tube, the simple theory predicts a noise figure of 11 db. The lowest noise figure obtained was 13 db, which suggested that some sort of a limit had been reached for this set of conditions. Despite this discouraging evidence, an attempt was made to obtain further reduction by increasing the helix voltage. The next tube, LN6, was identical with LN5 except for an increase in helix pitch. Its helix voltage was 2,000 rather than 1,200 volts. The 3-db improvement expected from doubling the voltage ratio of the velocity jump was not obtained. The lowest noise figure obtained was 16 db, which is 3 db higher than before. According to the simple theory, the noise figure should have been 8 db.

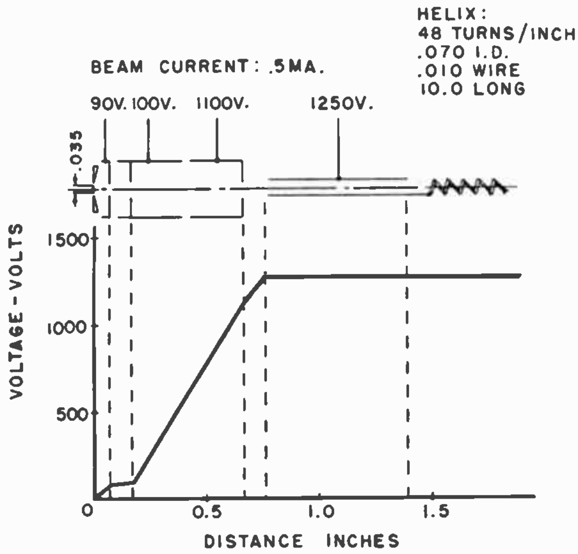


Fig. 7—Tube LN4, showing operating conditions for 14.5 db noise figure.

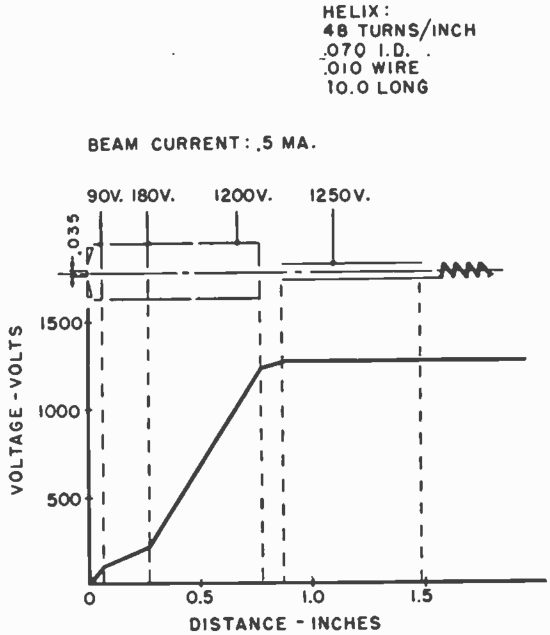


Fig. 8—Tube LN5, showing operating conditions for 13 db noise figure.

Our best experimental result, so far as noise figure is concerned, was obtained from LN7, shown in Figs. 9 and 10. Its design is similar to that of LN5, except that all dimensions are roughly scaled by a factor of two. The lowest noise figure obtained was 11.3 db at a net gain of 18 db. The simple theory predicts a noise figure of 9 db.

Variation of Noise Figure with Adjustable Parameters

Throughout the experiments with the low-noise tubes, attempts were made to correlate variation in noise figure with variations of operating voltages and other adjusta-

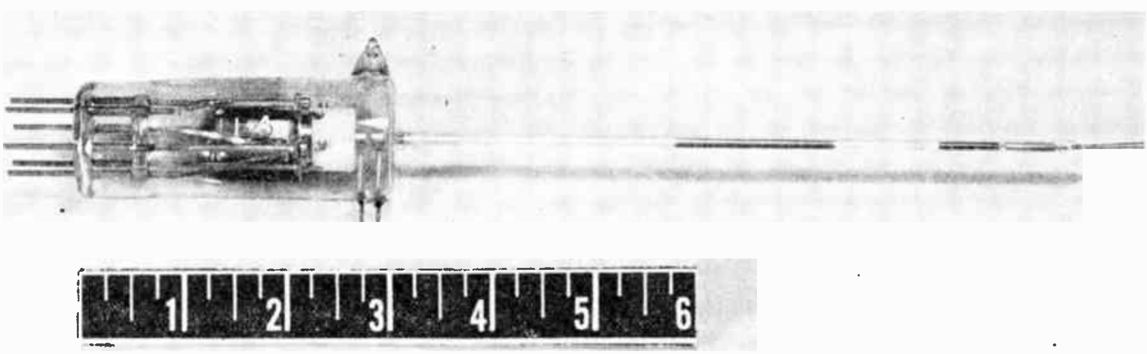


Fig. 9—Tube LN7.

ble parameters. The adjustment of the voltages on the noise-reducing electrodes was important as shown, for example, in Fig. 6. It was found important to reduce the current intercepted by electrodes prior to the collector

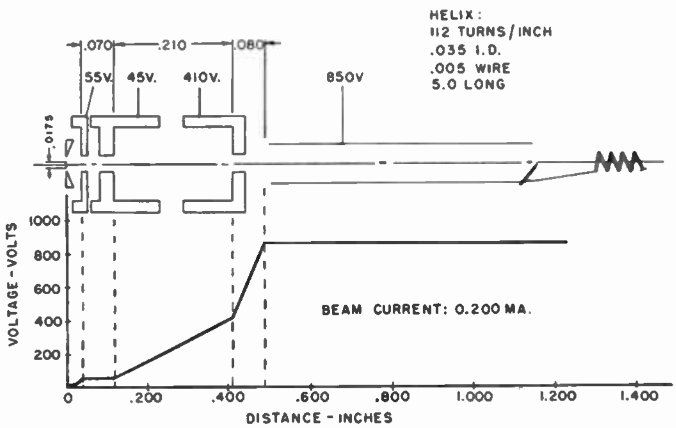


Fig. 10—Tube LN7, showing operating conditions for 11.3 db noise figure and 18 db gain.

in order to eliminate interception noise. Improving beam transmission beyond 99 per cent led to no reduction in noise figure, but improvement from 95 to 99 per cent was found to be important. This was achieved by changing the position of the tubes in the magnetic focusing coil and by adjusting the flux density of the magnetic field. It was found that there was no significant variation in noise figure with magnetic field, except through its effect on intercepted current. Some data in this connection are shown in Fig. 11 for LN4.

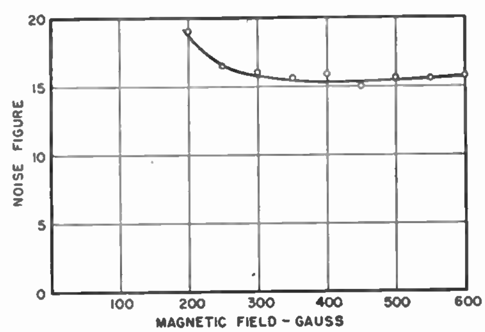


Fig. 11—Variation of noise figure with dc magnetic field for tube LN4.

Some interesting data on the variation of noise figure with cathode temperature are shown in Fig. 12. As the cathode temperature is lowered, the noise figure decreased slightly down to 1000 K, at which temperature it started to rise markedly. Although not apparent from the curve, it was roughly at this temperature that the cathode became temperature-limited as observed by a slight drop in beam current. This suggests that the deepening of the potential minimum and the increase in the number of electrons returned to the cathode by the potential minimum have little or no effect on the noise currents in the electron stream.

Variation of Noise Figure with Large Changes in Frequency

All of the tubes described here were designed and originally tested in the 8.5- to 9.6-kmc band. In addition, measurements of noise figure were made later on some of the single-jump tubes at 3.3 kmc and 4.4 kmc. The results, together with the corresponding values of helix voltage, V_H and C, are shown in Table I. In the first column are listed the design numbers of the tubes and the letters denoting the frequencies for which the rest of the data apply: X for 9,000, C for 4,400, and S for 3,300 mc. The tabulated noise figures are the smallest that could be obtained at the indicated frequency.

TABLE I

Tube	V_H (Volts)	C	V_HC	F
6, S	3600	0.0242	87.0	21.5
5, S	1470	0.0206	30.3	18.0
6, X	2350	0.0102	24.0	15.7
5, X	1250	0.009	11.3	12.8
7, X	870	0.0131	11.3	11.3
5, C	1180	0.0187	22.1	15.0

The variation of noise figure with frequency in these tubes is decidedly contrary to the prediction of the simple theory. For a given voltage at the anode, noise figure should be inversely proportional to V_HC, since all the other parameters remain substantially constant. The C is of course higher at the lower frequencies. The voltage is also higher due to the dispersive property of the helix.

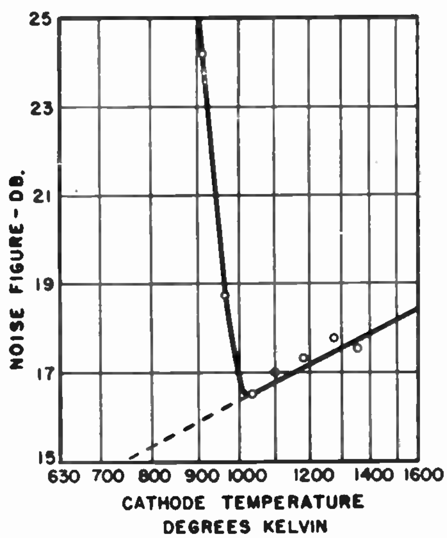


Fig. 12—Variation of noise figure with cathode temperature for tube LN1.

An Empirical Modification of the Simple Theory

If the noise figures, F, measured at the different frequencies (Table I) are plotted as a function of V_HC, the curve of Fig. 13 is obtained. There follows a possible explanation of the observed performance.

Consider the possibility that the noise figure for a single-jump, low-noise traveling-wave tube is given by the expression

$$F = 1 + \frac{1}{2}(4-\pi)\frac{T_c}{T}\,\frac{1+2\left(\frac{\omega_q}{\omega_p}\right)^2 V_1}{V_H C} f(QC, d, \delta z) + \frac{e}{KT}\Gamma^2 V_H C, \quad (3)$$

where, in mks units,

F = Noise figure
T_c = Cathode temperature (°K)
T = Ambient temperature (°K)
ω_q/ω_p = Plasma frequency reduction factor
V_1 = First anode and drift space voltage
V_H = Helix voltage
C = Pierce's traveling-wave tube gain parameter
$f(QC, d, \delta z)$ = A function of Pierce's space-charge parameter QC, loss parameter d, and the position of the helix entrance along the noise space-charge wave.
e = Electronic charge
K = Boltzmann constant
Γ^2 = Ratio of the mean-square noise convection current in the electron stream at the minimum of standing wave to full shot noise.

The first and second terms in (3) are those of the simple theory[1] applied to the single-jump tube. The last term was derived by Pierce in his first analysis of noise in traveling-wave tubes[10] by considering that, at the entrance to the helix, there exists a noise current in the electron stream of magnitude Γ^2 times full-shot noise. Equation (3) involves the assumption that the noise in an electron stream can be separated into two components which are mutually uncorrelated in time. This means, in effect, that the cathode produces an electron stream which contains (1) a component which excites a space-charge standing wave of noise current having perfect zeros, and (2) a noise current whose amplitude does not vary with distance, is not affected by velocity jumps and is uncorrelated with the first.

The justification for this assumption is that for all the points plotted in Fig. 13, the theoretical noise figures calculated from the simple theory—the first two terms of (3)—are negligible compared with the experimental value. Hence, the experimental results can be attributed, with small error, to the third term. If this is done, we find that the use of a value of 0.02 for Γ^2 in the third term gives a result which is within a decibel or so of the experimental values. This is not far from the values of the minima measured in the sliding cavity experiments[6,7] since $\Gamma^2 = 0.02$ corresponds to 17 db below full-shot noise.

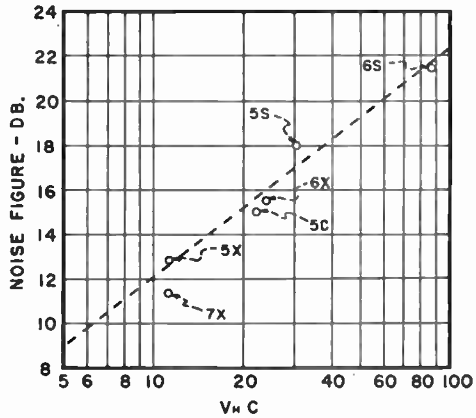


Fig. 13—Measured noise figure as a function of helix voltage times C for the tubes tested at different frequencies

Possibilities for Future Work

The foregoing empirical theory suggests that there are two methods by which noise figure can be lowered. The third term in the expression for noise figure can be reduced by reducing $V_H C$. The second term will then be increased, but this can be compensated for by reducing the anode voltage V_1 simultaneously. There is no theoretical limit to the amount of improvement obtainable by this method since, even for a gun of specified perveance, V_1 can be lowered, resulting in a lower beam current. The effect of lowering the current on the gain of the tube can be compensated for by making the helix longer.

The magnitude of the third term can also be reduced by decreasing Γ^2. Since there is as yet no theoretical evaluation of Γ^2, upon what it depends is not known. Examination of the results obtained from noise figure measurements on the various tubes at the different frequencies suggests that Γ^2 does not depend upon anode voltage, frequency, beam current, or beam current density, since these parameters were different for different tubes, whereas Γ^2 was nearly constant.

Other schemes that have been tried for reducing noise figure include arrangements in which it is attempted to adjust the entrance conditions for the helix so that no increasing wave of noise is set up. No positive experimental results have been reported, but that does not mean that they are unobtainable.

Acknowledgment

The writer is indebted to R. G. Rockwell for making most of the measurements on the low-noise tubes and supervising their construction. The tubes were ably built by J. J. Roberts and A. M. Anderson with assistance from other members of our Engineering Section.

[10] J. R. Pierce, "Theory of the beam-type traveling-wave tube," Proc. I.R.E., vol. 35, pp. 111–123; Feb., 1947.

An Analysis of Errors in Long Range Radio Direction Finder Systems*

JAMES G. HOLBROOK†, MEMBER, IRE

Summary—Modern radio direction finding equipment and techniques have advanced to such a degree that it is possible to obtain accurate bearings on a signal from halfway around the globe. These successes have resulted largely from recent electrical and mechanical refinements in the modern Adcock antenna df system.

Although the system has been described before, and applications demonstrated, to the writer's knowledge there has not been a complete investigation of its potentialities. An analysis would seem desirable because of the great utility of the system.

The following material develops a rigorous mathematical analysis of the errors that are mostly encountered in the design and installation of a new direction finding station. A detailed treatment of the effect of variations in the antenna spacing is presented in support of the author's recommendations for obtaining higher efficiency in the upper frequency ranges of a given station.

Introduction

THE FIXED Adcock direction finding system is described briefly in most engineering texts,[1–4] and may be pictured physically as a scaled down version of the familiar four tower radio range station. Each antenna normally uses a thin vertical wire as the pickup element, and will have some suitable method for aperiodic matching to a set of interconnecting transmission lines.

All direction finding systems are subject to some amount of electrical unbalance which invariably results in bearing errors. The objective here is to develop a mathematical analysis of the errors which are contributed by various antenna element spacings, so that this portion of the total residual error may be separated from that which is due to site irregularity.

Symbols

E_0 = Reference voltage measured at origin in Fig. 1.
E_N = Complex voltage measured at north antenna (Fig. 1).
E_S = Complex voltage measured at south antenna (Fig. 1).
E_{N-S} = Voltage from north-south antenna pair to goniometer.
E_{E-W} = Voltage from east-west pair to goniometer.
θ = Azimuth angle between N–S antenna and incoming signal (Fig. 1).
ϕ = Bearing as measured by goniometer.
C = Correction, normally equal to $\theta-\phi$.
k = Antenna diagonal spacing to wavelength ratio.
k' = Antenna spacing to wavelength ratio, effective.
ψ = Angle of vertical incidence of incoming wave, measured from horizontal.

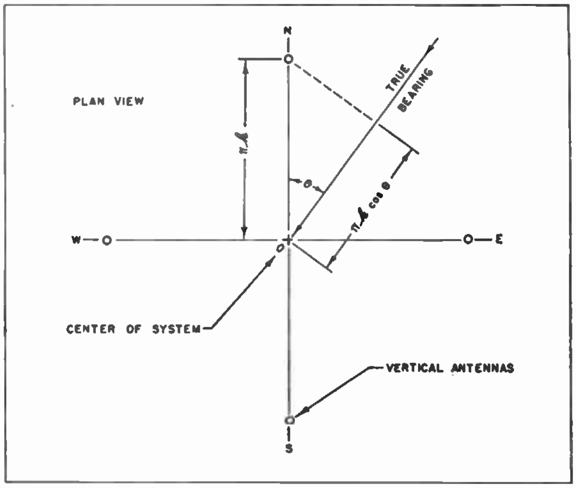


Fig. 1—Geometry of the fixed Adcock system.

Relations Between True and Observed Bearings

If the origin 0 in Fig. 1 is taken as a reference, the voltage at the north antenna is leading in phase and may be written as

$$E_N = E_0\epsilon^{j\pi k \cos\theta}.$$

The voltage at the south antenna will then be

$$E_S = E_0\epsilon^{-j\pi k \cos\theta}.$$

The combined output voltage is the difference, rather than the sum, because of the conventional cross-connection in the connecting transmission line, and is given as

$$E_{N-S} = E_0(\epsilon^{j\pi k \cos\theta} - \epsilon^{-j\pi k \cos\theta})$$

or, factoring out a $2j$,

$$E_{N-S} = 2jE_0 \sin(\pi k \cos\theta).$$

This may be normalized by letting $2jE_0=1$, whereupon the north-south pattern becomes

$$E_{N-S} = \sin(\pi k \cos\theta). \tag{1}$$

The east-west Adcock pair yields a similar expression

$$E_{E-W} = \sin(\pi k \sin\theta). \tag{2}$$

* Decimal classification: R501. Original manuscript received by the Institute, Dec. 5, 1952; revised manuscript received June 20, 1953.

† Northrop Aircraft, Inc., Hawthorne, Calif.

[1] R. Keen, "Wireless Direction Finding," Iliffe and Sons, Ltd., London, England; 1938.

[2] D. S. Bond, "Radio Direction Finders," McGraw-Hill, New York, N. Y.; 1944.

[3] J. G. Holbrook, "Null Characteristics of the Rotating Adcock Antenna System," *Jour. of Appl. Phys.*, vol. 24, pp. 530–532; May, 1953.

[4] P. G. Hansel, "Instant Reading Direction Finder," *Electronics*, vol. 21, pp. 86–91; 1948.

Now since the goniometer follows a true cosine law, the indicated bearing ϕ may be expressed implicitly as

$$\tan \phi = \frac{\sin (\pi k \sin \theta)}{\sin (\pi k \cos \theta)} \tag{3}$$

which relates ϕ and θ in terms of the mast spacing to wavelength ratio k. The application of (3) is seen by examining the curves of Fig. 2 for $k=0.5$, 0.6, 0.7, and 0.8. The only quadrant shown is 0° to 90°, as it is noted from (3) that each quadrant will be identical.

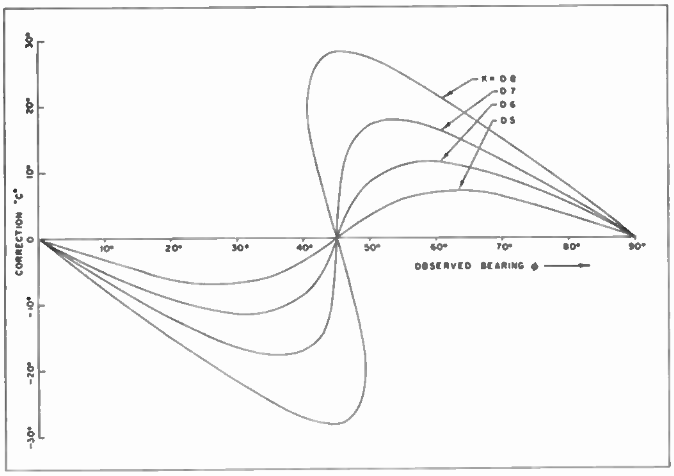


Fig. 2—Graph of equation (3).

General Interpretation of Error Curves

Fig. 2 shows that for very small values of k the curve becomes almost a sine wave, although for larger values the curve takes on a sawtooth characteristic which eventually becomes multiple valued. Since a practical long-range direction finder must cover the entire short-wave bands from perhaps 2 mc. to about 18 mc. or higher, choosing the value of k presents a problem.

If the value $k=0.5$ is chosen at a frequency of 18 mc. the system will have a very low sensitivity at the low frequency end of its range from (1), and yet if k be chosen as 0.5 at the lower frequency limit, the frequencies near the upper limit will all produce several ambiguous bearings from (3).

We will leave a discussion of compromise values of k until later. However, if a limiting value of k can be determined beyond which all bearings are ambiguous, it is seen that a compromise value can be chosen to meet the individual requirements of each df station.

Mathematical Analysis of Error Curves

Variation of correction with changes in observed bearing

Differentiating (3) with respect to θ gives

$$\frac{d\phi}{d\theta} = \frac{\pi k \cos \theta \sin (\pi k \cos \theta) \cos (\pi k \sin \theta) + \pi k \sin \theta \sin (\pi k \sin \theta) \cos (\pi k \cos \theta)}{\sec^2 \phi \sin^2 (\pi k \cos \theta)}. \tag{4}$$

To examine the point at 45° where the observed bearing ϕ changes most rapidly, the value $\pi/4$ will be substituted for both θ and ϕ above, which then reduces to

$$\left.\frac{d\phi}{d\theta}\right|_{\phi=\pi/4} = \frac{\pi k}{\sqrt{2}} \cot \left(\frac{\pi k}{\sqrt{2}}\right)$$

and inverting

$$\left.\frac{d\theta}{d\phi}\right|_{\phi=\pi/4} = \frac{\sqrt{2}}{\pi k} \tan \left(\frac{\pi k}{\sqrt{2}}\right). \tag{5}$$

Now the correction C is defined as $C=\theta-\phi$. Differentiating this:

$$\frac{dC}{d\phi} = \frac{d\theta}{d\phi} - 1 \tag{6}$$

and substituting the results of (5) into this equation gives

$$\left.\frac{dC}{d\phi}\right|_{\phi=\pi/4} = \frac{\sqrt{2}}{\pi k} \tan \left(\frac{\pi k}{\sqrt{2}}\right) - 1. \tag{7}$$

The significance of (7) may be demonstrated by the following examples: For $k=0.5$

$$\frac{dC}{d\phi} = 0.82.$$

Which represents a reasonably small variation in C as the observed bearing changes at or near 45°.
But for $k=0.65$

$$\frac{dC}{d\phi} = 4.3$$

and for $k=0.68$

$$\frac{dC}{d\phi} = 9.9$$

i.e., in the second case the correction varies 4.3°, and in the third case 9.9° for a 1° change in ϕ, and small observational errors are magnified in the ratios of 5.3 to 1 and 10.9 to 1 respectively.

In addition to the above, another point of interest is at $\phi=\theta=0°$, and will be discussed briefly. Substituting these values into (4) and inverting, gives:

$$\left.\frac{d\theta}{d\phi}\right|_{\phi=0} = \frac{\sin \pi k}{\pi k}$$

and substitution of this value into (6) gives

$$\left.\frac{dC}{d\phi}\right|_{\phi=0} = \frac{\sin \pi k}{\pi k} - 1. \tag{8}$$

The insertion of typical values of k will show that operation in the vicinity of 0° is much more stable than near 45° even though k may become rather large. This is readily seen in Fig. 2.

Skywave errors and angle of wavefront elevation

When the incident wave is inclined at an angle ψ to the ground, the effective mast spacing to wavelength ratio is:

$$k' = k \cos \psi. \qquad (9)$$

The expression for $dC/d\psi$ yields no results in simple form, and this type of error is therefore illustrated with an example.

From Fig. 2, if $k=0.7$, ψ assumed zero, and $\phi=37\frac{1}{2}°$, the correction is $-17\frac{1}{2}°$ and therefore $\theta=20°$, but if actually $\psi=30°$, the effective $k'=0.7 \cos 30°=0.6$ approximately, and for $\phi=37\frac{1}{2}°$ the true correction is $-10°$, making $\theta=27\frac{1}{2}°$. In practice it is not possible to assess the value of ψ and when k becomes large considerable errors can result, in the above case $7\frac{1}{2}°$.

Ambiguity of bearings

The results of an observation may be ambiguous in certain cases as is seen from the curve of $k=0.8$ in Fig. 2. This means that the same reading ϕ may be obtained for two or more values of θ. It becomes necessary therefore to determine mathematically what set of conditions must exist in order that (3) may have more than one solution for θ. An inspection of the curves again leads us to take 45° as a suitable point for investigation. At 45°, $\phi=\theta$ and $\tan \phi=1$, (3) therefore becomes:

$$\sin(\pi k \cos \theta) = \sin(\pi k \sin \theta)$$

for which the normal solution is

$$\cos \theta = \sin \theta$$

but since $\sin(180°-x)=\text{Sin } x$, another possible solution is:

$$\sin(\pi - \pi k \cos \theta) = \sin(\pi k \sin \theta)$$

from which

$$\sin \theta + \cos \theta = \frac{1}{k}. \qquad (10)$$

But from trigonometry

$$1 \leqq \sin \theta + \cos \theta \leqq \sqrt{2}$$

therefore

$$1 \leqq \frac{1}{k} \leqq \sqrt{2}$$

or

$$\frac{1}{\sqrt{2}} \leqq k \leqq 1.$$

This last expression therefore shows that when k is greater than 0.707 that (3) will be multiple valued at least for some values of θ, and the affected band is seen to spread rapidly on either side of $\phi=45°$ as k increases. The practical limit is therefore

$$k = \frac{1}{\sqrt{2}}. \qquad (11)$$

The critical value of θ for $1/\sqrt{2} \leqq k \leqq 1$ may be determined by setting (6) equal to infinity which sets the numerator of (4) equal to zero yielding (12) and solving graphically for θ.

$$-\tan \theta = \tan(\pi k \cos \theta) \cot(\pi k \sin \theta). \qquad (12)$$

For values of $k \geqq 1/\sqrt{2}$ the correction C is maximum at 45° points, and solving (10) for C gives:

$$C = \pm \cos^{-1}\left(\frac{1}{\sqrt{2}\, k}\right). \qquad (13)$$

When C reaches 45° all bearings correct to $\theta=0°$. This occurs when $k/\sqrt{2}=1/\sqrt{2}$, or at $k=1$ all bearings will become ambiguous.

Conclusion

It has been found that the observed bearing ϕ is only dependent upon the ratio of the E–W to the N–S response. Errors in observations become more serious as k increases. For any value of k in the vicinity of 0.5 or less the correction is reasonably small, but if k becomes much larger than about 0.5 the readings become increasingly erratic, especially in the area near 45° points. When k reaches $1/\sqrt{2}$ df is not usable near 45° points. As k rises above $1/\sqrt{2}$ some bearings become ambiguous, as k reaches 1 all bearings are ambiguous.

While it is felt that the foregoing material will be of special interest to designers and to those who are concerned with the initial installation and testing of stations, a clear understanding of the factors involved which cause unusual bearing variations should also promote interesting suggestions to the regular operating staff for increasing general efficiency of the station.

Doppler-Effect Omnirange*

PAUL G. HANSEL†, SENIOR MEMBER, IRE

Summary—**This paper describes an omnirange of a new design in which the transmitting antenna is caused either to move, or to appear to move along a circular path to produce low-deviation FM by Doppler effect. The FM envelope phase of the transmitted signal is directionally characterized. Deviation-expansion and selective-degeneration in an AFC circuit are used at the receiver to detect the minute directional FM in the presence of FM noise of much larger deviation. Advantages of the new omnirange include improved resolution, accuracy and ease of multiplexing.**

Introduction

ALL RADIO RANGES in general use are designed around directional antennas of small-aperture (less than $\lambda/2$). The instrumental accuracy and the course stability of these ranges are critically dependent upon the care exercised in construction, adjustment and siting and in spite of the utmost care, an omnirange of conventional design[1] still exhibits objectionally high bearing errors and fluctuations (course scalloping) on typical sites.[2,3] In some geographical zones, even if the equipment is installed on the best available site, nearby obstacles and reradiators may give rise to errors and course scalloping of magnitudes which seriously limit navigational reliability. As the use of omnirange navigation increases, the need for greater instrumental accuracy and for reduced site errors and course scalloping will become increasingly acute. The introduction of automatic flight computers[4] will further accentuate this need.

The instrumental accuracy of a conventional omnirange cannot be greatly improved since it is mechanically impracticable to achieve a significantly closer conformity to the intended law of operation through more precise manufacture and balancing. Recent studies have indicated that site errors and course scalloping can be reduced by greatly increasing the antenna aperture.[5,6,7] However, in a spaced-aerial directional system, this benefit is achieved at the price of ambiguities and spacing errors. A possible solution of the ambiguity problem of a wide aperture system is to use a fine/coarse system with a wide aperture antenna to produce accuracy, and a narrow aperture antenna to resolve the ambiguity. This solution, however, introduces a further problem of excessive complexity in the receiving equipment.

These problems are avoided in a new form of omnirange which was devised in 1945[8] and demonstrated experimentally in 1949. The high angular resolution and consequent error reduction characteristic of wide aperture systems are obtainable without ambiguity or spacing error. There exists no fundamental limit on antenna aperture. The instrumental accuracy is inherently high because the law of operation is easy to satisfy with simple instrumentation. In addition, the new omnirange has challenging multiplex possibilities which permit the transmission of navigational information in the sub-audible portions of communication channels or even of broadcast channels.

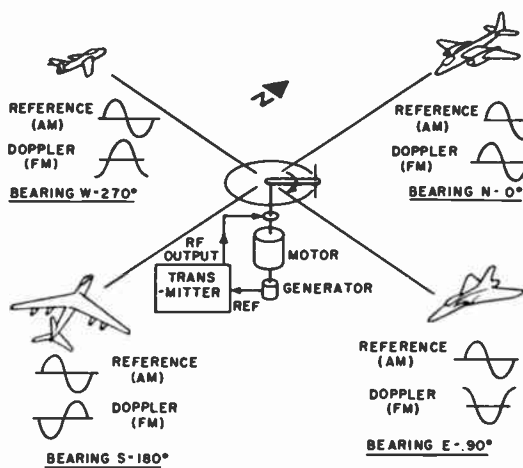


Fig. 1—Doppler omnirange.

Operating Principle

The new omnirange is based upon an application of Doppler effect and, in a modification of the system, upon a quasi-Doppler effect. No azimuth directivity is used in the antenna system. Instead, directional information in the form of sub-audible frequency modulation is imposed upon the transmitted signal by radiating the signal from a point on the circumference of a horizontal circle and continuously revolving the point around the center of the circle at a slow rate. Revolution of the radiation source can be accomplished at the higher frequencies by actually whirling the antenna as shown in Fig. 1 to produce directionally-characterized Doppler

* Decimal classification: R526.12. Original manuscript received by the Institute, August 27, 1952; revised manuscript received July 9, 1953.

† Servo Corporation of America, New Hyde Park, N. Y.

[1] H. C. Hurley, S. R. Anderson, and H. F. Keary, "The civil aeronautics administration VHF omnirange"; Proc. I.R.E., vol. 39; pp. 1506–1520; December, 1951.

[2] S. R. Anderson and H. F. Keary, "VHF omnirange wave reflections from wires"; Tech. Development Rep. no. 126; C.A.A. Tech. Development and Evaluation Center, Indianapolis, Ind.; May, 1952.

[3] W. R. Rambo, J. S. Prichard, D. P. Duffy, and R. C. Wheeler, "Summary report on evaluation of omni-bearing—distance system of air navigation"; Rep. no. 540-1, Air. Instrument Lab., Inc.; October, 1950.

[4] E. H. Fritze, "Punched-card controlled aircraft navigational computer"; Proc. I.R.E., vol. 41, pp. 734–742; June, 1953.

[5] W. Ross, "Fundamental problems in radio direction finding at high frequencies (3–30 mc/s)"; J.I.E.E., vol. 94, part IIIA, pp. 154–165; 1947.

[6] C. W. Earp, "Radio direction finding by cyclical differential measurement of phase"; J.I.E.E., vol. 94, part IIIA, pp. 705–721; 1947.

[7] J. L. L. Boulet, J. M. Anderson, and T. R. O'Meara, "Doppler-Type Direction Finding"; Tech. Rep. no. 8; Radio Direction Finding Res. Lab., Dept. of Elect. Eng., Univ. of Illinois; October 1, 1948.

[8] P. G. Hansel, "Navigation System"; U. S. Patent No. 2,490,050; filed November 7, 1945, issued December 6, 1949.

effect. At low frequencies where antennas are large, a quasi-Doppler effect can be produced in the manner illustrated in Fig. 2, by applying the transmitter output through a commutator in rapid succession to fixed-position radiators.

The actual or virtual motion of the radiating source imposes a sinusoidal frequency modulation upon the transmitted signal. The envelope phase of this modulation as observed at a distant receiver is a continuous function of the direction from the transmitter to the receiver.

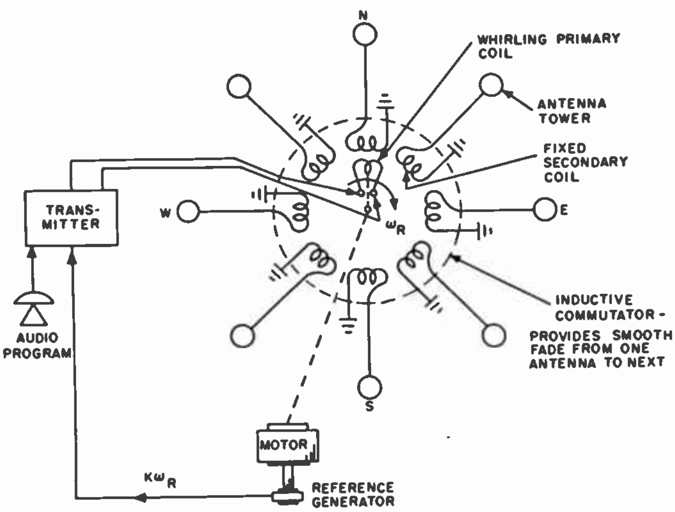


Fig. 2—Quasi-Doppler omnirange using commutated array of fixed antennas.

When the radiating antenna is effectively revolving about the center of a circle the field E_X acting upon a receiver at a distant point X in the same horizontal plane may be expressed by an equation of the form:

$$E_X = E_M \sin\left[\omega_c t - \frac{\omega_c d}{C} + \frac{\omega_c R}{C}\cos(\omega_r t - \alpha)\right], \quad (1)$$

where ω_c is the angular frequency of the transmitter carrier; d is the distance from the center of revolution to point X; R is the radius of the circle; C is the velocity of propagation; α is the direction from the transmitter to point X measured clockwise from North; and ω_r is the angular velocity at which the transmitting antenna is revolved about the center of the circle.

The effective instantaneous frequency f_e of the wave received at point X is equal to the rate of change of phase so

$$f_e = \frac{1}{2\pi}\frac{d}{dt}\left[\omega_c t - \frac{\omega_c d}{C} + \frac{\omega_c R}{C}\cos(\omega_r t - \alpha)\right], \quad (2)$$

$$f_e = f_c\left[1 - \frac{\omega_r R}{C}\sin(\omega_r t - \alpha)\right], \quad (3)$$

where $f_c = \omega_c/2\pi$.

The instantaneous frequency observed at a distant receiver varies sinusoidally about the carrier frequency at a rate equal to the effective rate of revolution of the transmitting antenna. The envelope phase of this frequency modulation is equal to the direction from the transmitter to the receiver. The maximum frequency deviation Δf is:

$$\Delta f = \frac{f_c \omega_r R}{C}. \quad (4)$$

If the point of reception, X, is moving with a radial component relative to the transmitter there will also be a non-periodic Doppler increment of frequency of $f_c(v/C)$ where v is the radial velocity component.

The direction from the transmitter to the receiver can be determined at the receiver by measuring the envelope phase of the Doppler-imposed frequency modulation. This measurement requires a reference-phase signal which can be provided most simply by amplitude-modulating the transmitter at some low frequency rate which is harmonically-related to the effective antenna revolution rate. More complex methods may have advantages under certain circumstances. For example, an FM reference might be preferable in multiplexed low-frequency operation to reduce static and to avoid interference with normal AM program modulation.

When an AM reference is used the signal observed at the distant receiver, neglecting multiplexed program or message modulation, has the form:

$$E_X = E_M \sin\left[\omega_c t - \frac{\omega_c d}{C} + \frac{\omega_c R}{C}\cos(\omega_c t - \alpha)\right] \cdot [1 + A\sin K\omega_r t], \quad (5)$$

where A is the amplitude modulation index and K may be either a fractional or an integral constant.

Reference ambiguity is avoided if the reference frequency is equal to or is a sub-harmonic of the antenna revolution rate. A convenient practical value for the constant K is $\frac{1}{2}$.

The signal represented by (5) is completely directionally characterized since it is possible to receive this signal at a single point in space and to translate the periodic variations of amplitude and frequency into directional information. The phase and depth of the amplitude modulation are substantially independent of direction whereas, as previously explained, the envelope phase of the frequency modulation is equal to the direction from the transmitter to the receiver.

Description of Experimental Equipment

An operating frequency of 351 mc was chosen for the first tests of the Doppler omnirange since a transmitter and a frequency assignment were available in this frequency range. At this frequency a whirling antenna is just as practicable mechanically as the equivalent commutated array of fixed antennas and was chosen, in preference to the latter arrangement, because of its greater simplicity.

Both a high revolution rate and a large radius are desirable to maximize the Doppler deviation and to achieve the resolution advantages associated with a large aperture. However, the mechanical stresses are proportional to the square of the revolution rate and to the first power of the radius so, to achieve a given deviation, it is preferable to minimize the revolution rate and maximize the radius.

With these considerations in mind, the antenna for this project was designed with a one-meter boom length and a revolution rate of 885 rpm (14.75 rps). At 351 mc these parameters provide a Doppler frequency deviation of ± 108.5 cps and an aperture of 2.34 λ. This is approximately 9 times the aperture permissible in a conventional omnirange at this frequency.

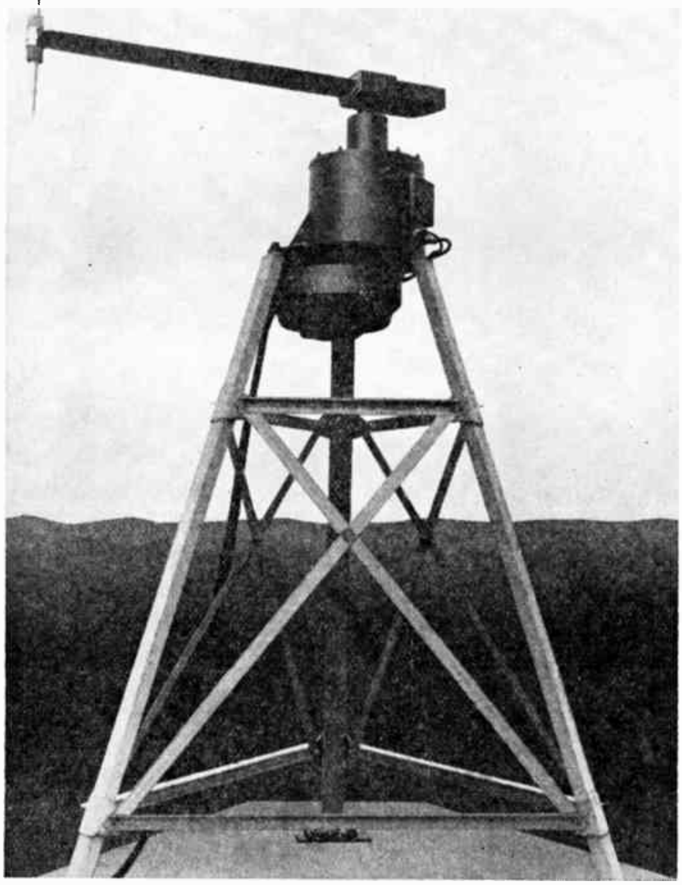


Fig. 3—Revolving antenna for experimental Doppler omnirange.

Fig. 3 is a photograph of the antenna system developed. A $7\frac{1}{2}$ horsepower, three-phase, 220-volt motor operating at a speed of 1750 rpm drives the horizontal boom at $\frac{1}{2}$ the motor speed through gears enclosed in the cast housing. A permanent-magnet alternator mounted inside the housing is driven at full motor speed to supply a fixed-phase amplitude-modulation reference signal having a frequency of 29.5 cps. The original plan was to drive the alternator at half speed to provide a sub-audible reference of 7.375 cps. However, the transmitter available could not be modulated at such a low rate so the reference frequency was made twice the revolution rate, simply for experimental convenience.

Radio frequency power from the transmitter is fed through a rotary transformer to a half-wave dipole antenna at the end of the boom. The transformer comprises a pair of coaxial rings, one attached rigidly to the housing and the other rotating with the boom.

A. Receiver and Indicator Design

Fig. 4 shows a simplified block diagram of the receiver. The receiver is a conventional amplitude modulation receiver with data-extraction circuits fed from the last IF amplifier. The function of data extraction is performed by the steps of limiting, expanding the deviation, and then detecting in an FM discriminator. Feedback through a selective automatic frequency-control loop corrects for tuning errors and degenerates unwanted FM components. The bearing indicator is a phase meter and the circuits used are, in most respects, similar to those used in the standard CAA omnirange receiving equipment.

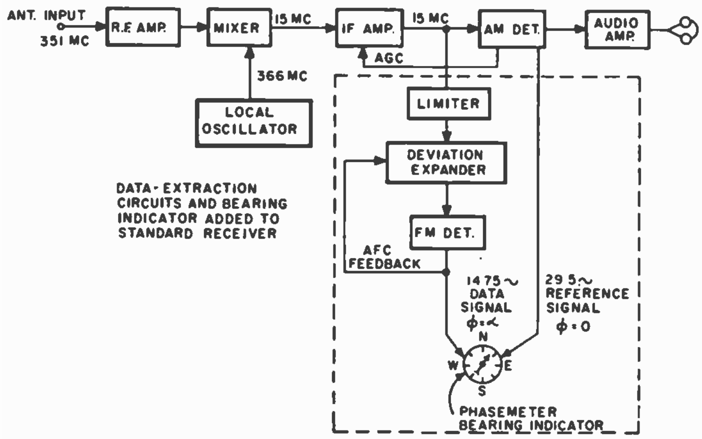


Fig. 4—Simplified block diagram of receiver.

Fig. 5 shows the receiving installation with the receiver on the right and the azimuth selector and left-right meters on the left. The unit in the center contains the bearing indicating and data extraction circuits, together with a regulated power supply and built-in field measurement facilities designed as experimental aids.

B. Deviation-Expansion and Data-Extraction

The deviation-expansion and data-extraction method for the Doppler or FM channel is illustrated in block diagram form in Fig. 6. The 15 mc IF signal from the receiver is applied first to an AM detector to recover the reference phase signal of 29.5 cps. The 15 mc signal is also applied to a limiter which removes most of the amplitude modulation, and in addition, serves as a tripler with its plate circuit tuned to 45 mc. The 45 mc signal from the limiter-tripler is heterodyned in a mixer with a local oscillator signal of 45.450 mc and the nominal difference frequency of 450 kc is amplified in an IF amplifier and then applied to an FM discriminator.

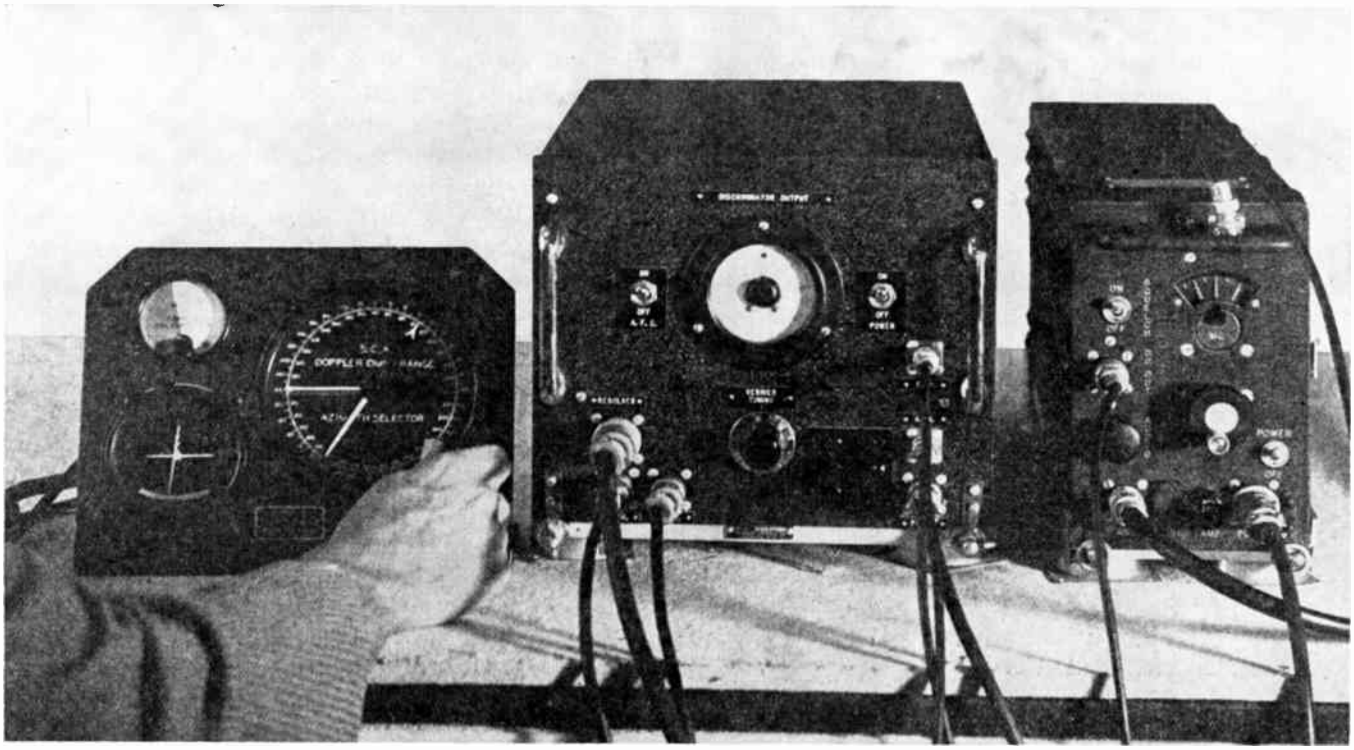


Fig. 5—Receiving equipment.

The discriminator output comprises a DC component proportional in magnitude and polarity to the detuning of the receiver, a 14.75 cycle Doppler-envelope signal and a group of periodic and transient signals representing FM noise.

The significant feature of the signal-to-noise ratio problem at the output of the FM detector is that the *directional information is contained entirely in the narrow-band variations in the phase of the 14.75 cps Doppler envelope signal*, and that practically all noise components present are either DC or have frequencies different from the frequency of the FM information signal. This difference in frequency permits the use of discrimination through frequency-selective automatic frequency control of the local oscillator in the data-extraction circuit. This is accomplished by feeding the detector output, through a null filter tuned to reject 14.75 cps, to a reactance tube which in turn controls the frequency of the local oscillator.

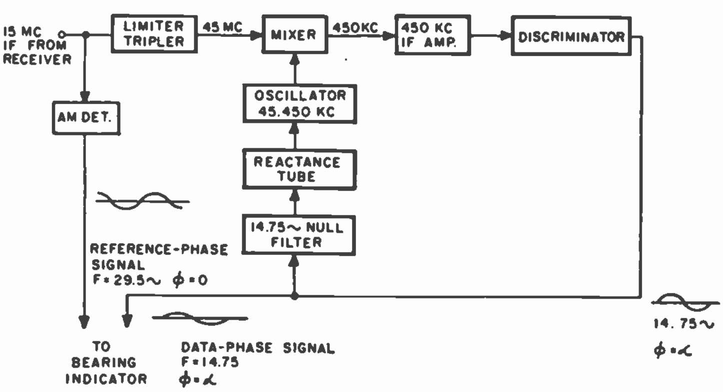


Fig. 6—Deviation-expansion and data-extraction method.

The AFC filter is shown in Fig. 7. Its function is to pass a DC error component representing detuning, to reject the 14.75 cps data signal and to pass all frequencies at which FM noise is likely to be severe. FM noise with a modulating frequency higher than approximately 150 cps ordinarily has a deviation well within the bandwidth of the FM detector and can therefore be removed largely by filtering after detection instead of by degeneration before detection.

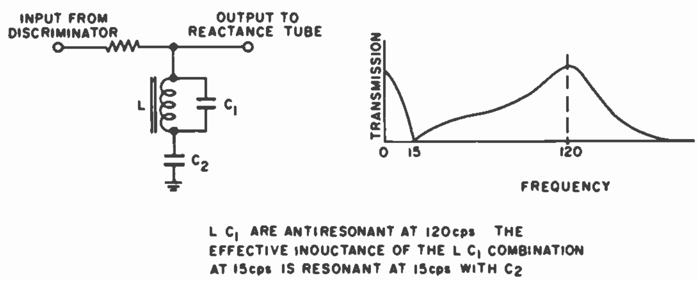


Fig. 7—Alternate filter for AFC loop.

The deviation-expansion technique used in this equipment to detect extremely low-deviation FM is analogous to amplification and involves frequency multiplication to increase absolute deviation and heterodyning to increase deviation factor. *The signal at the receiver input has a Doppler deviation of only 108.5 parts in 351 million.* Conversion in the receiver to the intermediate frequency of 15 mc does not increase the absolute deviation in cycles per second but it does increase the *deviation factor* $\Delta F/F_o$ 23.4 times.

The process of multiplying the intermediate frequency by three and then converting to 450 kc further multiplies the deviation factor 100 times. The total deviation-expansion (or FM amplification) accomplished is therefore 2,340 times.

C. Bearing Indicator

The bearing indicator is a phase meter for measuring the phase between the fixed-phase AM reference modulation and the directionally-characterized Doppler FM.

The reference modulation of the experimental system has twice the frequency of the Doppler modulation so the indicator design includes a frequency doubler between the FM detector and the phase meter circuits.

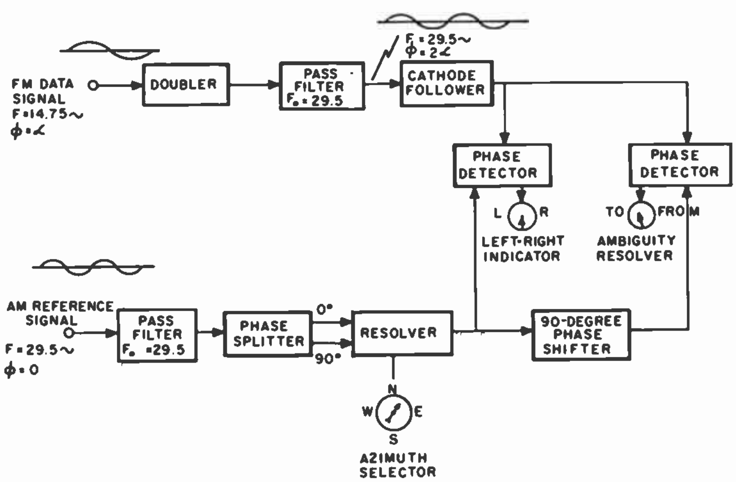


Fig. 8—Bearing indicator and course selector.

Fig. 8 is a block diagram of the bearing indicator. It will be noted that this indicator is functionally identical with the CAA VOR indicator except for the frequency doubler. The filters used are shown in Fig. 9. In essence,

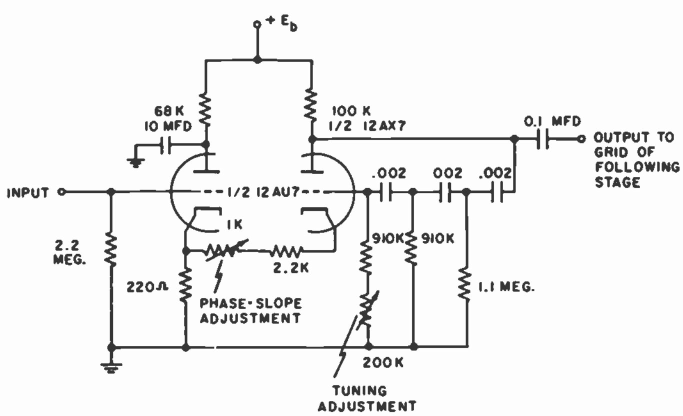


Fig. 9—Regenerative pass filter with adjustments for phase-curve slope and tuning frequency.

the filter is a phase-shift oscillator requiring a voltage gain of about 28 for oscillation. The bias circuit is adjusted to permit a maximum gain of about 25. The circuit is therefore highly regenerative at the tuned frequency but cannot become unstable. The slope of the phase characteristic of this filter can be varied by changing the gain of the regenerative stage with the bias control. This provides a simple way for compensating for changes in the speed of the antenna drive motor.

The scale on the resolver is expanded so that a full revolution of the pointer represents a bearing change of only 180 degrees instead of the usual 360 degrees. An expanded scale was particularly useful in the experimental work because of increased indicating resolution.

Experimental Results

A. FM Noise

The principal objective in developing the experimental system was to determine the practicability of deriving bearing data from the phase of the low-deviation Doppler FM in the presence of larger-deviation FM noise.

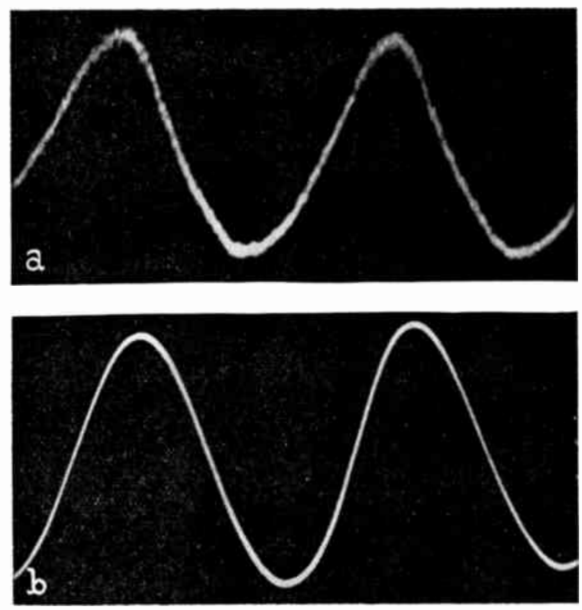


Fig. 10—29.5 cps AM (reference-phase) signal with 20 μV receiver input modulated approximately 35 per cent. (a) Output of AM detector before filtering. (b) Output of AM detector after filtering.

Frequency drift amounted to a maximum of 10 kc in the transmitter and 25 to 50 kc in the receiver. Periodic FM noise deviations of 2 kc in the transmitter and 15 kc in the receiver were experienced. Transient FM noise deviations had a maximum value of 2 kc in the transmitter and 5 to 10 kc in the receiver, the latter being due principally to microphonic vibration of the ganged tuning condenser and would not be present in a crystal-controlled receiver.

The selective AFC system was able to degenerate all drift and FM noise deviations to values well within the 5 kc knee-to-knee bandwidth of the FM detector, and, because of the additional selectivity of the audio filters in the bearing indicator, extraneous frequency modulation which was definitely periodic in character presented practically no problem at all.

Fig. 10 shows the reference signal output of the AM detector before and after filtering. Fig. 11(a) shows the discriminator output with the AFC circuit disabled.

Fig. 11(b) provides a striking illustration of the effectiveness of the AFC in eliminating the strong 60 cps and 120 cps FM noise present in the raw discriminator output. The Doppler envelope after doubling and filtering is shown in Fig. 11(c).

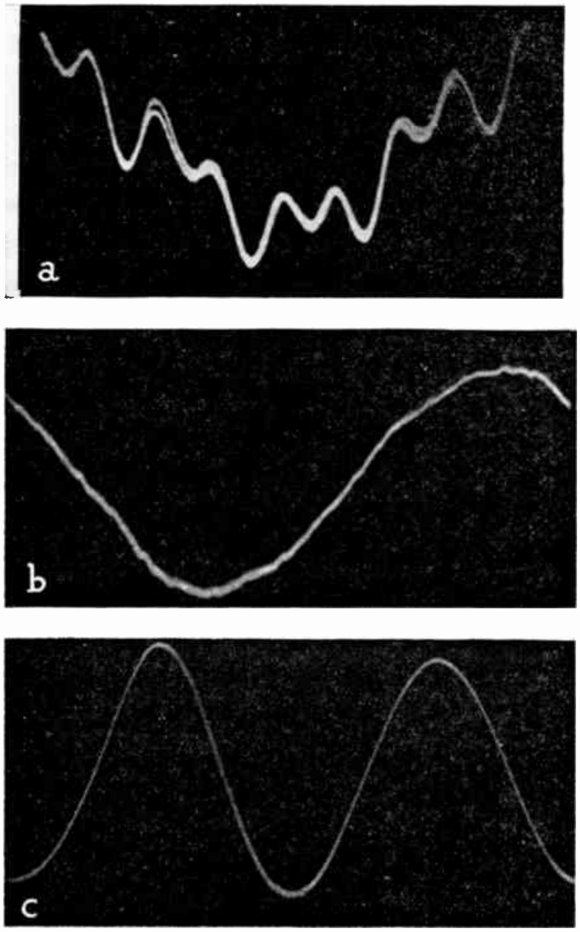


Fig. 11—Doppler envelope (data-phase) signals with 20 μV receiver input. (a) 14.75 cps discriminator output with AFC loop open. Note large 60 cps and 120 cps "noise" superimposed on 14.75 cps Doppler envelope. (b) 14.75 cps discriminator output with AFC loop closed. The 60 cps and 120 cps FM "noise" is substantially eliminated. (c) Doppler envelope after doubling to 29.5 cps and filtering.

B. Instrumental Accuracy

The whirling antenna was installed on the roof of a building in Lindenhurst, New York and the receiving equipment shown in Fig. 5 was installed in an automobile. Road tests in the vicinity of Lindenhurst were conducted over a two-month period for the purpose of studying accuracy and practical problems.

The area directly north of the transmitter site was fairly clear and the signal received in this area was uniformly strong. In all other directions reception was too poor because of buildings and power lines to permit meaningful observations at ground level. For this reason measurement work was confined to the northern sector.

Instrumental accuracy was determined by repeatedly measuring the azimuth difference between two fixed points as the orientation of the whirling antenna was changed by small steps. The fixed points were three miles from the transmitter and 14.5 degrees apart in azimuth. In this test the bearing indicator accuracy proved to be the limiting factor. The maximum errors observed ranged from 0.5 degree to 1.0 degree and were attributed largely to the indicator. An attempt was made to eliminate indicator errors by calibration but it was found that repeatability better than 0.5 degree could not be obtained with this indicator design. It was concluded that any errors present in the transmitted signal were definitely less than 0.5 degree in magnitude.

C. Multiplexing

Throughout the road tests the omnirange transmitter was amplitude modulated by voice to provide communication with the test car. Whirling the transmitting antenna did not affect the quality of the AM voice modulation except in the fringe zones. The 29.50 cps reference modulation did not interfere with voice communication because of its low level and because the audio gain of the receiver was sharply attenuated below 50 cps.

Conclusions

On the basis of the work performed to date, the following conclusions appear to be justified:

1. The instrumental practicability of the Doppler omnirange has been demonstrated.
2. Detection of low-deviation Doppler FM in the presence of FM noise of higher-deviation is not a particularly difficult problem.
3. The instrumental accuracy of the Doppler omnirange is high. More refined indicating equipment will be required to determine just how high.
4. Verification of the site-error suppression predicted for large aperture antennas will require more extensive and better controlled investigations.
5. Multiplexing with AM voice communication can be accomplished simply.

Application Possibilities

The Doppler omnirange could be used to provide a new VHF or UHF navigational service or it might be modified[9] in a simple manner to provide a high-precision VHF service fully compatible with the existing CAA VHF omnirange (VOR). Large aperture "VOR-Compatible" Doppler omniranges could be used at difficult sites to reduce site errors and course scalloping without any change in existing airborne receiving equipment.

The ease with which the Doppler omnirange can be multiplexed with an existing AM program service makes it technically possible to use standard AM broadcast stations as low frequency omniranges. It has been seriously proposed that a selected group of clear-channel broadcast stations be converted, as illustrated in Fig. 2,

[9] P. G. Hansel, "Two-Frequency VOR-Compatible Doppler Omnirange"; Appendix A of Servo Corporation of America Report No. SCA-1000-1; March 10, 1950. (This modification was suggested to the author by Mr. Harry Davis of the Rome Air Development Center, Rome, N. Y.).

into high-power quasi-Doppler omniranges. This would make possible the establishment of a long-range low-frequency navigational service which otherwise might not be feasible because of economic and frequency-allocation considerations.

ACKNOWLEDGMENT

The Doppler omnirange was devised in 1945 while the author was an employee of the Signal Corps Engineering Laboratories and was developed in 1949 under Air Force Contract No. AF28(099)-27.

Relaxation Oscillations in Voltage-Regulator Tubes*

P. L. EDWARDS†, ASSOCIATE, IRE

Summary—**Gas-filled voltage-regulator tubes are subject to relaxation oscillations when operated in parallel with a condenser. These oscillations have been investigated and a qualitative description of their mechanism is presented. It was found that the voltage across the tube as a function of current has a minimum, and that if the current through the tube is greater than that at the voltage minimum, then relaxation oscillations do not occur. It was also found that a 100-ohm resistance in series with a VR105 tube reduces the tube current required to prevent oscillations.**

INTRODUCTION

GAS FILLED vr (voltage regulator) tubes, such as the VR105 or the VR150 are used mainly for two purposes, voltage reference and voltage regulation. As a voltage reference, the vr tube is operated at nearly constant current. The tube under such operating conditions is subject to instantaneous fluctuations of voltage and slow drifts with time which have been investigated and reported in some detail.[1]

As a voltage regulator, the tube is in parallel with the load, and operates with fluctuating current. It is well known that a condenser placed in parallel with a vr tube will improve its regulation. It is also equally well known that such a condenser often causes relaxation oscillations, rendering the tube useless as a regulator. It is the purpose of this paper to give a simple qualitative explanation of why such oscillations occur, and how they may be prevented.

MECHANICS OF OSCILLATION

Fig. 1 shows the regulator circuit with the condenser C in parallel with the vr tube. The current equation at the plate junction is

$$i_2 = i_1 - i_3, \tag{1}$$

and in terms of the voltage across the condenser,

$$i_2 = C\frac{dE}{dt}, \tag{2}$$

where E is the voltage across the vr tube and condenser. With the tube conducting and in equilibrium—that is, constant current through and constant voltage across the tube—

$$\frac{dE}{dt} = 0 \tag{3}$$

and

$$i_1 = i_3. \tag{4}$$

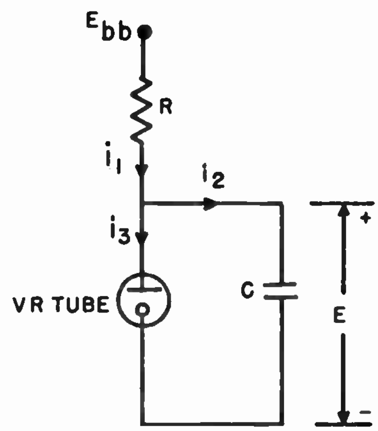


Fig. 1—Voltage-regulator tube with parallel condenser.

In Fig. 2(a) is shown the current-voltage characteristic of a vr tube. The current-voltage characteristics of vr tubes will be discussed later, but for now assume the characteristic of Fig. 2(a). Also shown is the load line for the circuit, which is determined by

$$i_1 = \frac{E_{bb} - E}{R}, \tag{5}$$

where R and E_{bb} are shown in Fig. 1. The intersection of the load line and the vr tube characteristic determines the stable operating point of the tube, for it is there that (4) is satisfied.

Consider now the path of the point (E, i_3) when E_{bb} is first applied. The vr tube does not conduct. The current through R charges the condenser and increases the voltage E across both the tube and condenser. This is indicated on the current-voltage plot, Fig. 2(b), by the path AB. At B the striking potential of the tube is

* Decimal classification: R141.4×R338.2. Original manuscript received by the Institute, December 15, 1952; revised manuscript received June 8, 1953.

† U. S. Naval Ordnance Laboratory, White Oak, Silver Spring, Md.

[1] G. M. Kirkpatrick, "Characteristics of certain voltage-regulator tubes," PROC. I.R.E., vol. 35, pp. 485–489; May, 1947.

reached, and the tube begins to conduct. The current immediately jumps from zero to about a hundred milliamperes; that is, to the value at C. The tube current is then greater than i_1 and the condenser begins to discharge. The (E, i_3) point then continues down the tube characteristic until the load line is reached at D. At D the point stops because $i_1 = i_3$ and so, $dE/dt = 0$. It should be noted that as long as the point (E, i_3) is on the tube characteristic to the right of the load line, then i_3 is greater than i_1 and the condenser voltage is decreasing, for from (1) and (2),

$$\frac{dE}{dt} = -\frac{i_3 - i_1}{C}. \tag{6}$$

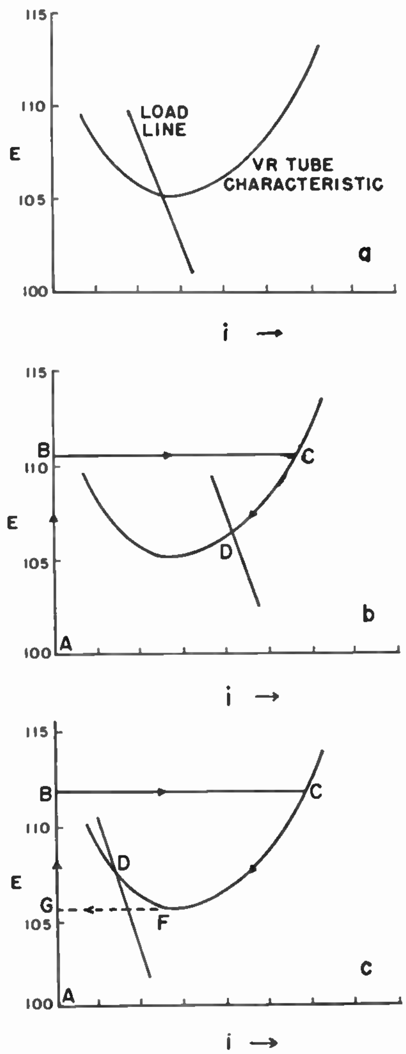


Fig. 2—In (a) the tube characteristic and load line are shown. The path of the point (E, i_3) is shown in (b) for the case of the intersection D on the high-current side of the tube-characteristic minimum, and in (c) for D on the low current side.

Consider now the locus of the point (E, i_3) when E_{bb} is first applied for the case of Fig. 2(c). The load line now intersects the tube characteristic on the low current side of minimum. When E_{bb} is first applied, the path and operation are the same as in Fig. 2(b) from A to B and from B to C. The point does not traverse the path from C to D, however, for when the minimum (point F) is reached, the slope of the tube characteristic is zero, which requires that $dE/dt = 0$. If the current i_3 decreased still further, then dE/dt would have to become positive. This cannot occur, for on the right of D the tube current, i_3, is greater than i_1, and by (6) dE/dt must be negative. Since the voltage E cannot increase along the path from F to D, the tube characteristic cannot be followed, and the tube ceases to conduct. Thus the path taken in this case is from F to G rather than from F to D. From G the point moves toward B and the cycle is repeated, with relaxation oscillations resulting.

The above discussion of relaxation oscillations explains the mechanism of their generation. With this mechanism in mind it is possible to develop schemes to

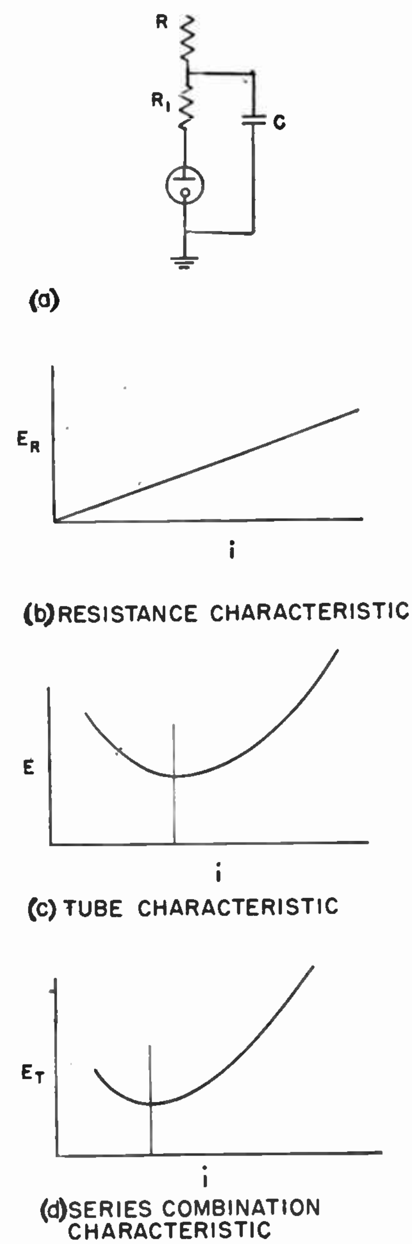


Fig. 3—In (a) the resistance R_1 is placed in series with the vr tube of the regulator circuit. The characteristics of the resistance (b) and tube (c) in series add to give the combined characteristic (d). The minimum of the series combination occurs at a lower current than does that of the tube alone.

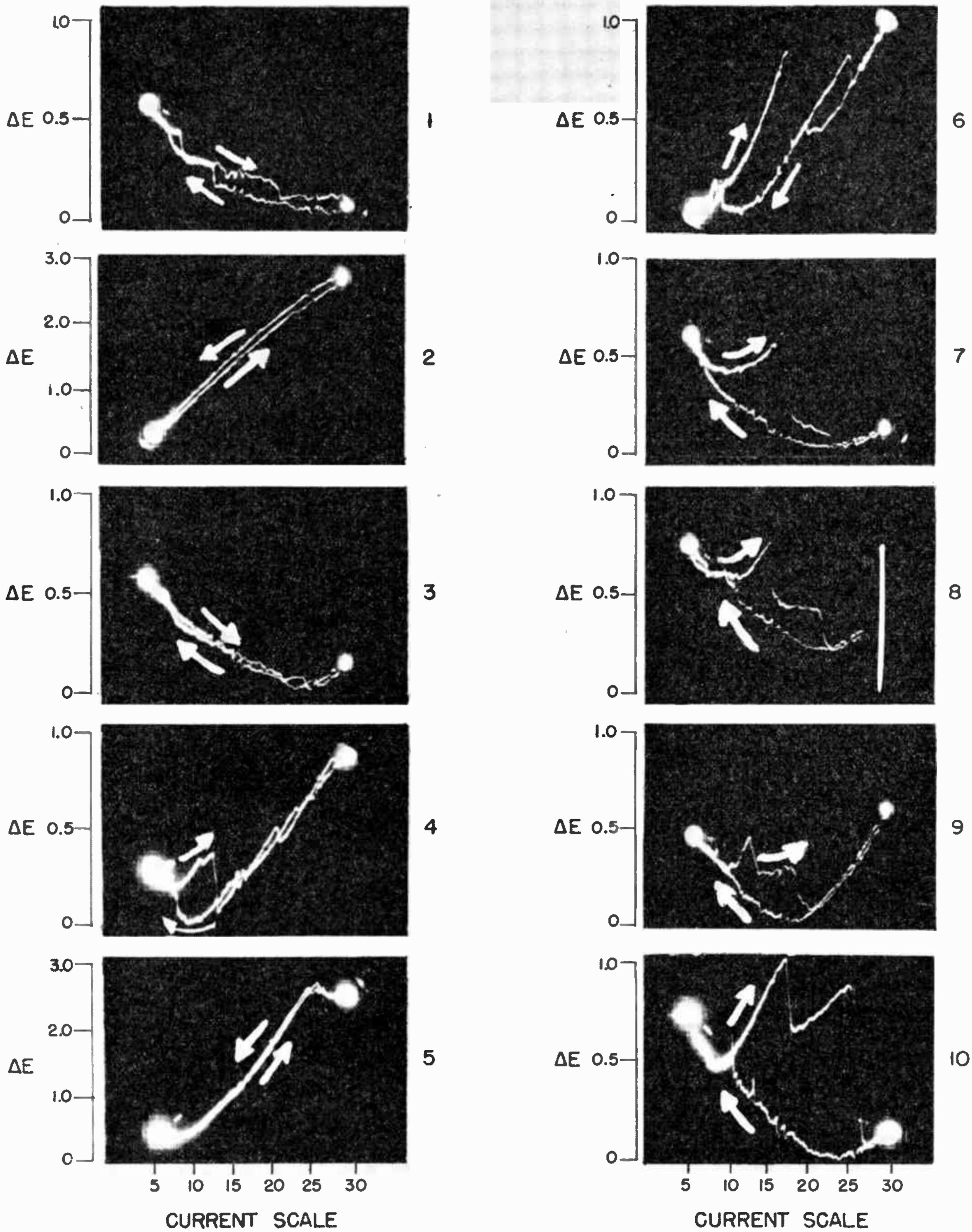


Fig. 4—Current-voltage characteristics for ten vr105 voltage-regulator tubes. The arrows indicate the direction of current change. The voltage ΔE is in volts and the current i is in milliamperes. Note that the voltage scale is not the same in all cases. These tubes were taken from those at hand in the laboratory. No effort was made to obtain a representative sampling from various manufacturers and for different operating voltages.

prevent the oscillation. The most direct procedure is to arrange R and/or E_{bb} so that the intersection D occurs on the high-current side of the minimum F. Also a vr tube might be picked with a minimum at a lower current. It is also possible to place a resistance in series with the tube and shift the point F of the series combination to a lower current, Fig. 3.

Current-Voltage Characteristics of VR Tubes

The experimental current-voltage characteristics of ten tubes (VR105) are shown in Fig. 4. To obtain these curves the tube current was varied by manual rotation of a potentiometer; the sweep from 5 to 30 milliamperes and back took about one second.

From the curves of Fig. 4 several interesting properties of vr tubes are apparent.

(a) The characteristics of vr tubes vary greatly from tube to tube.

(b) The current-voltage characteristic of a vr tube depends in a remarkable manner on the direction of change of the current.

(c) The curve for decreasing current is smoother and has fewer abrupt changes than that for increasing current. In the above relaxation oscillation discussion, only the curve for decreasing current is important. These curves agree qualitatively with the curve assumed in Fig. 2.

(d) Above a certain current, depending on the tube, the curves for increasing and decreasing current are nearly coincident and are fairly smooth.

Further tests which are not reported here, indicated that the tube characteristics exhibit minor variations from day to day. Though the characteristics also show changes with frequency, the decreasing current characteristic, which is the important one from the point of view of relaxation oscillations, shows little change up to the highest frequency tested, 80 cps.

Relaxation Oscillation Tests

The circuit of Fig. 5 was used in the relaxation oscillation tests. With the plate supply "on" the tube current was decreased by increasing the series resistance, until relaxation oscillations began. The tube current (strictly speaking, the average tube current) was then increased until the oscillations ceased. For still higher currents, within the normal operating range of the tube, the circuit was stable. The currents for three representative tubes at which the oscillations ceased are listed in Table I

TABLE I

Current through VR Tubes Required to Stop Relaxation Oscillations for Various Values of Parallel Capacity C

vr Tube Number	1 μf	4 μf	10 μf	30 μf	80 μf
2	4 ma	4 ma	4 ma	4 ma	4 ma
7	6	14	14	14	20
9	6	14	12	14	15

for several values of capacity. A comparison of Table I and Fig. 4 reveals that for the tubes listed, the relaxation oscillations always ceased for currents at or on the low current side of the minimum. This was true for all tubes tested. Thus for a given vr tube one may make certain that the tube will not oscillate by passing through it a current greater than that at the minimum of the current-voltage characteristics. This means that D, Fig. 2, must occur on the high-current side of the minimum F, as was previously discussed.

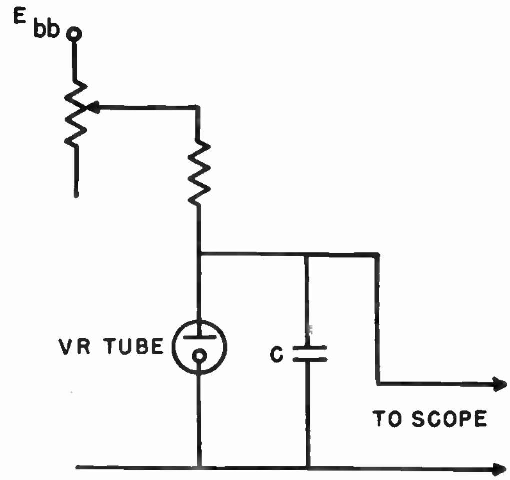


Fig. 5—Circuit for relaxation-oscillation tests. The milliampere meter used for measuring the tube current is not shown.

The minimum in the tube characteristics may be shifted to lower current values by insertion of a series resistance and considering the characteristics of the combination, Fig. 3. The tube characteristics show slopes below the minimum which can be compensated to about 5 milliamperes with a resistance of 50 to 100 ohms. Exact compensation is not feasible. The data of Table II were obtained in the same manner as those of Table I, but with the resistance R_1 in series with the tube as in Fig. 3. From these data it is apparent that R_1 in shifting the minimum to the left, reduces current through tube required to prevent relaxation oscillations.

TABLE II

Current through VR Tubes Required to Stop Relaxation Oscillations for Various Values of Parallel Capacity C and Series Resistance R_1

vr Tube Number	R_1 Ohms	Parallel Capacity, C				
		1 μf	4 μf	10 μf	30 μf	80 μf
2	0	2 ma	4 ma	4 ma	3 ma	4 ma
	50	2	3	3	2	3
	100	2	4	2	2	3
7	0	4	16	18	18	22
	50	4	10	10	10	11
	100	4	6	6	6	6
9	0	5	12	12	14	16
	50	4	10	8	8	9
	100	4	5	6	6	6

A comparison of Table I with Table II ($R_1=0$) indicates how well these measurements agree from day to day.

The experimental current-voltage locus was observed on a cathode-ray oscilloscope and differed in some respects from the curve *GBCFG* of Fig. 2(c). Along the path *GB* the current was not quite zero. A dark current of a few microamperes was flowing. This current was very small at *G* increasing approximately linearly with voltage to about 50 microamperes at *B*. The curve from *B* to *C* was concave downward, due to inertial effects within the tube. Also, the tube did not abruptly cease conducting at *F*, but due to the availability of ions and the sluggishness of the tube the locus left the tube characteristic between *F* and *D*.

Sinusoidal Oscillations

From Fig. 4 it is seen that the vr tubes have a region of negative resistance as indicated by the negative slope of the tube characteristics. With such a negative resistance element there is the possibility of sinusoidal oscillations, and during the above tests such oscillations were often observed. No detailed study was made of these oscillations, but the following facts were noted:

(a) The oscillations were unstable and would often increase in amplitude and throw the circuit into relaxation oscillations. The relaxation oscillations, being of a different mechanism would be of a different frequency and greater amplitude.

(b) The amplitude of the sinusoidal oscillations was normally one volt or less, whereas the amplitude of the relaxation oscillations might be as high as 20 v.

(c) The sinusoidal oscillation frequencies observed were from 15 to 200 cps.

(d) The "equivalent" inductance of the vr tube was found to vary from 1.5 henry at 15 cps and 5 milliamperes down to 0.06 henry at 200 cps and 20 milliamperes tube current.

Conclusions

Relaxation oscillations in vr tube are to be expected if the tube is shunted by a condenser and the load line intersects the tube characteristic curve on the low current side of the minimum. The oscillations can be prevented by arranging for the intersection to occur to the right of the minimum. This can be done for a given tube by decreasing the resistance *R*, Fig. 1, and moving the load line so the intersection occurs at sufficiently high current; or it can be done by placing a resistance in series with the tube to move the minimum to the low current side of the intersection.

Correction

R. H. Baker, I. L. Lebow, R. H. Rediker, and I. S. Reed, authors of the paper, "The Phase-Bistable Transistor Circuit," which appeared on pages 1119–1124 of the September, 1953 issue of the Proceedings of the I.R.E., have brought the following corrections to the attention of the editors:

Figure 9 and 11 should be interchanged.

The second line in equation (1) should read: $F\oplus G = F'G+FG'$.

On page 1123 $[t_j, t_j+\epsilon$ should read $[t_j, t_j+\epsilon)$ in the third line from the bottom and also in the bottom line.

In the second line in the left-hand column of page 1124 t_j should read p_j. In the third line $(t_j+\sigma, t_j+\epsilon+\sigma)$ should read $[t_j+\sigma, t_j+\epsilon+\sigma)$.

The second and third paragraphs of page 1124 should read: The pulse function $\alpha(t)$ is the product of $a(t+\sigma)$ and $\phi(t)$. An information pulse in $a(t+\sigma)$ allows a write pulse in $\alpha(t)$ and the lack of an information pulse inhibits a write pulse to appear in $\alpha(t)$. In other words if $a(t_j)=I$, a write pulse occurs in $\alpha(t)$ at time p_j, and if $a(t_j)=0$, no write pulse occurs in $\alpha(t)$ at time p_j.

The pulse function $\alpha_c(t)$ is $\alpha(t)$ mixed with the read pulse function ρt, or

$$\alpha_c(t) = \alpha(t) + \rho(t).$$

Antennas Fed by Horns*

B. BERKOWITZ†, MEMBER, IRE

Summary—**Formulas are derived for the E- and H-plane radiation patterns of antennas fed by horns as functions of illumination taper. The case of a single lens or reflector antenna fed by two contiguous horns stacked in either one of the principal planes is then investigated. By means of an illumination factor defined in terms of physical dimensions, the following electrical properties are related: (a) loci of half-power beamwidths, zeros, and side lobe peaks, (b) illumination taper at edge of secondary antenna, (c) crossover power, (d) spillover power, and (e) gain referred to the feed horn.**

Introduction

BOUNDARIES of the foreseeable future lie so near to the present that it is purely the author's good fortune to have analyzed, in unpublished work done at Sperry during 1947, a specialized class of microwave antennas in which interest continues high today. This important family of microwave antennas is categorized by the use of electromagnetic horns as feeds for the illumination of larger, secondary lens or reflector radiators. Popularity enjoyed by the horn in this usage stems primarily from the ease with which its beamwidths in the electric and magnetic planes may be independently controlled. Commonly, two or more feed horns are stacked contiguously in the focal plane of the secondary radiator for purposes of generating overlapping secondary beams. The electrical characteristics of such antennas will be investigated following the earlier analysis.

In the interest of deriving formulas in closed form, certain simplifying assumptions and approximations have been made. These are pointed out as they occur, and it is indicated how compensating corrections may be applied, in some instances, to achieve a wider degree of applicability of the end results. While rigour has thus been sacrificed, experience in using the derived equations indicates that over the range of validity of the approximations the prediction of the data is quite good.

Primary Patterns

The case of two horns stacked contiguously in the E plane and the nomenclature to be followed are depicted in Fig. 1.

Assuming separability, the normalized radiation field in each of the principal planes can be approximated by

$$f_E \cong \frac{\sin \pi b s/\lambda}{\pi b s/\lambda}, \tag{1a}$$

and

$$f_H \cong \frac{\cos \pi a s/\lambda}{1 - (2as/\lambda)^2}, \tag{1b}$$

where $s = \sin \phi$. Equations (1) agree reasonably well with the main lobe of measured horn patterns when the horn flare angles are small and the aperture dimensions each exceed a wavelength. While (1a) and (1b) are not new,[1] they are shown in Fig. 2 because they serve later to define the illumination factor α.

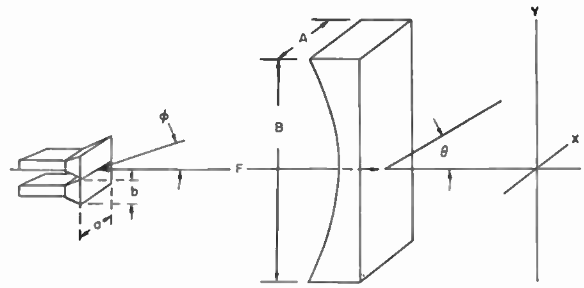


Fig. 1—Contiguous horns feeding antenna.

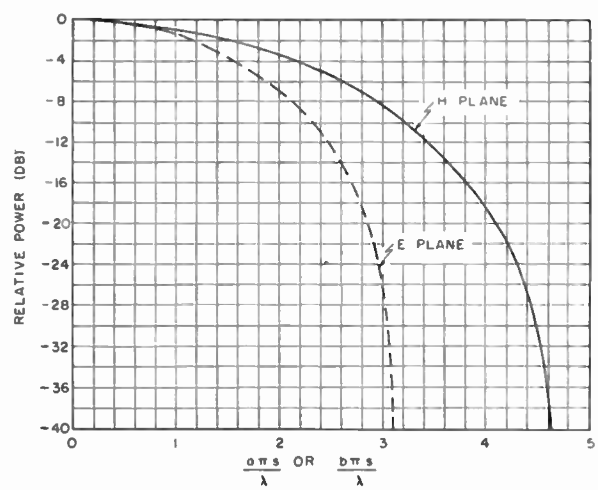


Fig. 2—Horn patterns.

Secondary Patterns

Obviously, the illuminated face of a secondary antenna may assume a large variety of configurations. Accordingly, (1a) and (1b) have been chosen to serve directly as separable illumination functions for the generalized secondary planar aperture. This choice requires that a correction be applied to account for the manner in which the character and shape of the illuminated antenna face modifies the illumination taper. The correction consists in selecting a modified value for

* Decimal classification: R326.8. Original manuscript received by the Institute, November 7, 1952; revised manuscript received June 9, 1953.

† Sperry Gyroscope Co., Division of the Sperry Corp., Great Neck, L. I., N. Y.

[1] J. R. Risser, "Microwave Antenna Theory and Design," McGraw-Hill Book Co., Inc., New York, N. Y., chap. 10; 1949.

α according to the methods to be described subsequently. In many cases the correction is small, and the graphs apply directly.

Equations (1) can be cast into a form better suited for describing the secondary antenna illumination. For this purpose the illumination factor, α, is defined as a numeric having the value of the abscissa in Fig. 2 whose ordinate equals the illumination taper (illumination at the edge of the antenna relative to that at its center). Referring to Fig. 1 the approximation may be made, for the E-plane case, that one replaces sin ϕ by tan $\phi = y/F$. At the edge of the antenna aperture, $y = B/2$, so that by substituting in (1a) one obtains for the illumination taper at the edge of aperture

$$f(B/2) = \frac{\sin \pi bB/2\lambda F}{\pi bB/2\lambda F}.$$

Therefore, in accordance with our definition for α,

$$\alpha_E = \pi bB/2\lambda F, \qquad (2a)$$

$$\alpha_H = \pi aA/2\lambda F, \qquad (2b)$$

where the expression for α_H follows a derivation similar to that for α_E. Using the approximate value for s and (2a) and (2b), the aperture distributions for the principal planes of the antenna may be written.

$$G(y) = \frac{\sin 2\alpha_E y/B}{2\alpha_E y/B}, \qquad (3a)$$

$$G(x) = \frac{\cos 2\alpha_H x/A}{1 - (4\alpha_H x/\pi A)^2}, \qquad (3b)$$

since possible phase variations across the aperture are ignored entirely because it is assumed that the secondary antenna corrects the spherical wave incident upon it to a uniform phase front. The secondary radiation fields are then represented by the integrals

$$F_E(S) = \int_{-B/2}^{B/2} G(y) \exp(jkyS) dy, \qquad (4a)$$

$$F_H(S) = \int_{-A/2}^{A/2} G(x) \exp(jkxS) dx. \qquad (4b)$$

Equations (4a) and (4b) may be manipulated into sine-integral and cosine-integral forms, convenient tables of which exist.[2] In this form, they become

$$F_E(S) = B/2\alpha_E [Si(u + \alpha_E) - Si(u - \alpha_E)], \qquad (5a)$$

where

$$u = \pi BS \div \lambda,$$

$$S = \sin \theta,$$

and

$$F_H(S) = \frac{A\pi}{8\alpha_H} \left\{ \cos \frac{\pi V}{2\alpha_H} [Si(m^+) - Si(n^+) - Si(m^-) + Si(n^-)] + \sin \frac{\pi V}{2\alpha_H} [Ci(m^-) - Ci(n^-) - Ci(m^+) + Ci(n^+)] \right\}, \qquad (5b)$$

where

$$V = A\pi S/\lambda$$

$$m = \pi/2 + \alpha_H$$

$$n = \pi/2 - \alpha_H,$$

and

$$m^+ = m(V/\alpha_H + 1)$$

$$m^- = m(V/\alpha_H - 1)$$

$$n^+ = n(V/\alpha_H + 1)$$

$$n^- = n(V/\alpha_H - 1).$$

Despite the formidable appearance of (5b) for the H-plane patterns in contrast with the simplicity of (5a) for the E-plane, close similarities exist. If corresponding values of α_E and α_H are chosen from Fig. 2, representing equal edge tapers in both principal planes, then the functions (5) are virtually coincident throughout the main lobe region. Therefore, only (5a) is plotted in Fig. 3. Magnitudes of the side lobe peaks, however, differ considerably depending upon the illumination function, and so the peak value of the first side lobes in the H-plane are also displayed in Fig. 3.

Apparently the main lobe region of (5a) also represents with fair accuracy a wide class of practical illumination functions when α_m, a modified value for α, is selected corresponding with the edge taper of the function. This property may be utilized partly to compensate for the departures in actual illuminations from the distributions given by (1a) and (1b). Alterations in illumination taper due to the effects of space attenuation, to reflections at lens inter-faces due to normal and oblique incidence or refraction of energy, to modification of the primary pattern due to curvature of the secondary antenna face, and to mismatch at lens surfaces, may be lumped together in arriving at α_m. Manner in which these effects may be taken into account to correct feed illumination function has been discussed in.[3]

Loci of the half-power beamwidths, zeros, and side-lobe peaks of (5a) are of interest. Sines of the half-power beamwidths, $S_{1/2}$, are found by solving the normalized form of (5a), with

$$F_E(S_{1/2}) = \sqrt{1/2} = [Si(u + \alpha_E) - Si(u - \alpha_E)] \div 2Si(\alpha_E) \qquad (6)$$

where $2Si(\alpha_E)$ is the normalizing constant.

[2] Tables of Sine-Cosine and Exponential Functions, prepared by the Federal Works Agency as Project No. 765-97-3-10.

[3] J. R. Risser, *op. cit.*, ch. 11.

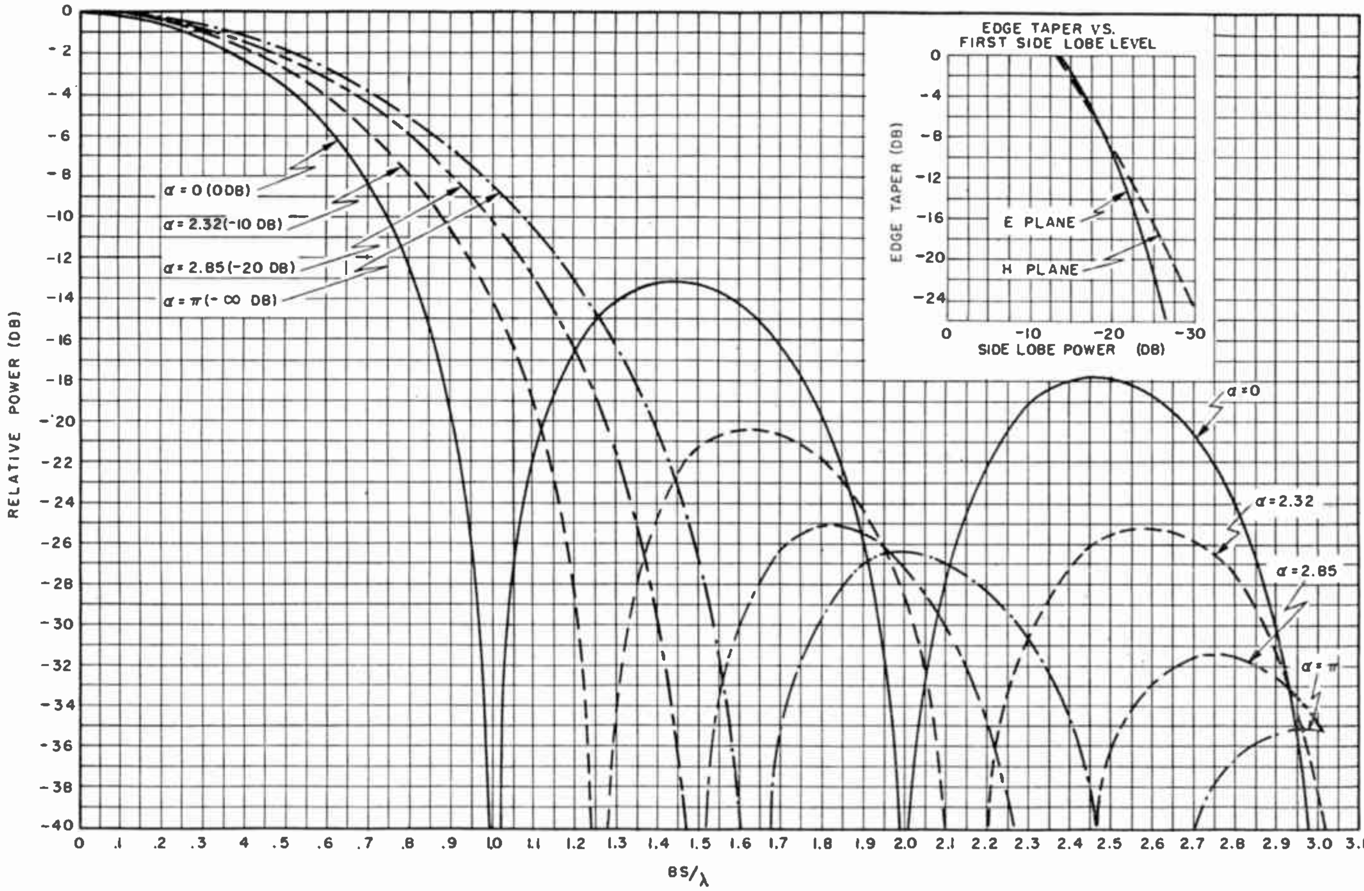


Fig. 3—E-plane patterns of an antenna fed by a horn.

By differentiating (5a) with respect to u and equating to zero, the two equations

$$Si(u + \alpha_E) = Si(u - \alpha_E) \tag{9a}$$

and

$$\sin (u + \alpha_E)/u + \alpha_E = \sin (u - \alpha_E)/u - \alpha_E \tag{9b}$$

are found from which the loci of zeros and side lobe peaks may be calculated. Loci of all these parameters also apply approximately for the H plane when corresponding values of α are used as explained above.

Crossover Power

Two or more beams may be generated in space by illuminating one common antenna aperture with several feeds mounted in the focal plane of the antenna. The main lobes of such beams usually overlap, and the energy level at which overlap occurs with equal intensity in both beams is known as crossover power. Of most interest is the maximum possible crossover power for two identical horn feeds displaced equally from the focal axis. This occurs when the horns are contiguous.

Angular deviation of the secondary beam, θ, with displacement of the feed in the focal plane is nearly but not quite equal to the angle ϕ. The ratio of the former of these two angles to the latter is known as the beam deviation factor,[4] here designated as d. The sine of the crossover angle, S_x, for the E-plane case, may be replaced by its tangent with but little loss in accuracy since θ is generally quite small. Thus

$$S_x = \sin (\phi d) \cong \frac{bd}{2F},$$

and therefore, at crossover

$$u_x = \frac{B\pi S_x}{\lambda} = \frac{d\pi Bb}{2\lambda F} = d_E\alpha_E.$$

Following a similar derivation for the H-plane case, one establishes secondary definitions of α as

$$\alpha_E = \frac{1}{d_E}\,\frac{B\pi S_x}{\lambda}, \tag{8a}$$

$$\alpha_H = \frac{1}{d_H}\,\frac{A\pi S_x}{\lambda}. \tag{8b}$$

Substituting these values into the normalized form of (5a) and (5b) we deduce for the power at crossover in the principal planes as

$$P_E(S_x) = [Si\{\alpha_E(d_E + 1)\} - Si\{\alpha_E(d_E - 1)\}]^2 \div 4Si^2(\alpha_E), \tag{9a}$$

[4] J. R. Risser, *op. cit.*, p. 488.

and

$$P_H(S_x) = \left[\frac{\ln(p) - \ln(q) + Ci(2q) - Ci(2p)}{2\{Si(p) - Si(q)\}}\right]^2, \quad (9b)$$

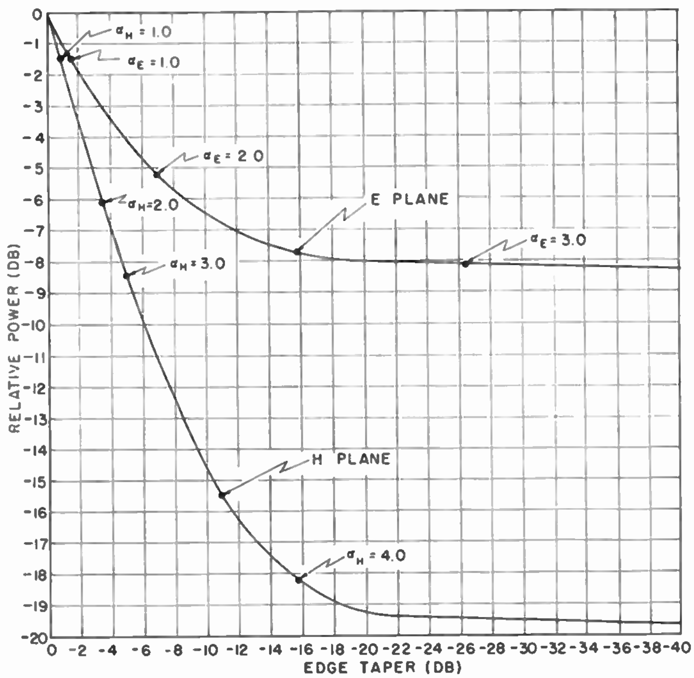
where

$$p = \frac{\pi}{2} + \alpha'_H$$

$$q = \frac{\pi}{2} + \alpha'_H$$

$$\alpha'_H = d_H\alpha.$$

Equations (9a) and (9b), with $d=1.0$, are plotted in Fig. 4 as functions of edge taper instead of α in order to emphasize the lower values for crossover achievable in the H-plane for the same edge taper as compared with E-plane. As functions of $d\alpha$ two curves are much alike.



B. POWER AT CROSSOVER FOR d = 1.0

Fig. 4

Special attention must be given to the manner in which α_m is used when cognizance must be taken of aperture taper modifications. Direct substitution of α_m for α in the crossover equations leads to erroneous results. The proper correction is easily applied, but its justification requires an explanation. Suppose that a matched lens is illuminated by two identical contiguous horns, this situation leading to the crossover results already obtained. Now assume the surface matching to be altered so as to vary the illumination taper by reflecting more energy at the lens edge than at its center. The greater illumination taper causes the secondary beams to broaden, and to raise the level at crossover.

The proper procedure for correction is: Enter Fig. 4 to determine $P'(\theta_x)$ from α_p, the particular, uncorrected value of α, and locate these as co-ordinates on Fig. 3. (The point so determined lies on the curve for $\alpha=\alpha_p$ since $\alpha_p = B\pi S_x/\lambda$.) Next, estimate where the curve $\alpha=\alpha_m$ crosses the same ordinate, $\alpha_p = B\pi S_x/\lambda$. The power level so determined, $P''(\theta_x)$, is the corrected crossover power if $d=1$; if not, the difference $P''(\theta_x) - P'(\theta_x)$ must be added as a correction to the uncorrected value.

Spillover Power and Gain

A reduction in gain can be expected due to loss of energy from the feed which spills past the edge of the antenna without striking it. However, the over-all effect on antenna gain as a function of edge taper depends not only upon the spillover loss, but upon the secondary beamwidths as well, and it should be noted that these two effects operate in opposite directions. One desires to know explicitly how spillover power and gain vary as functions of α.

The fractional part of feed-horn power which strikes the antennas as compared with the total power radiated is approximately expressed by

$$\frac{P_A}{P_T} \cong \frac{\int_0^{B/2} G^2(y)dy \int_0^{A/2} G^2(x)dx}{\int_0^{\infty} G^2(y)dy \int_0^{\infty} G^2(x)dx}, \quad (10)$$

where the G-functions are given by (3). While evaluation of the E-plane integrals in terms of known functions follows readily, the H-plane integral in the numerator does not. However, the $G^2(y)$ function may be used approximately to represent the H-plane distribution as well, provided an appropriate corresponding value of illumination factor, α_c, is chosen. If this is done,

$$\frac{P_A}{P_T} = \frac{4}{\pi^2}\left[Si(2\alpha_E) - \sin^2\alpha_E/\alpha_E\right]\left[Si(2\alpha_c) - \sin^2\alpha_c/\alpha_c\right], \quad (11)$$

which is plotted in Fig. 5 for the particular case $\alpha_E = \alpha_c$.

Equation (11) is approximate in two regards, the error becoming smaller in both cases as b/λ gets larger. First, integration of power is indicated only over the forward plane, with rearward radiation neglected. Equations (3a) and (3b) do not even predict correct values for back radiation. However, if a/λ and b/λ are equal to or greater than 2.0 it may be estimated that the side lobe energy neglected by (11) causes an error smaller than 0.3 db. Second, the replacement of sin (k sin θ) by sin (k tan θ) in (3a) and (3b) causes an additional error. If the value of the argument, k tan θ, is restricted to a range less than π, this contribution to error is less than 0.15 db whenever a/λ and b/λ are equal to or greater than 2.0.

The gain of the secondary aperture is defined as

$$G_A = \frac{4\pi}{\lambda^2}\frac{\left|\int_0^{B/2} G(y)dy \int_0^{A/2} G(x)dx\right|^2}{\int_0^{B/2} G^2(y)dy \int_0^{A/2} G^2(x)dx}, \quad (12)$$

and the gain referred to the feed horns, G_F, which takes spillover loss into account, is the product of (10) with

(12). By taking this product, the H-plane integrals over variable limits cancel, thus permitting a closed evaluation. One then arrives at

$$G_F = \frac{8AB}{\alpha_E \alpha_H \pi \lambda^2} Si^2(\alpha_E)\{Si(m) - Si(n)\}^2. \quad (13)$$

For convenience in expressing (13) in decibels, E- and H-plane components are separated by

$$G_F = \Gamma_E + \Gamma_H + 10 \log \frac{AB}{\lambda^2},$$

where $$\Gamma_E = 10 \log \left[4Si^2(\alpha_E)/\alpha_E\sqrt{\pi}\right], \quad (14)$$

and $$\Gamma_H = 10 \log \left[2\{Si(m) - Si(n)\}^2/\alpha_H\sqrt{\pi}\right].$$

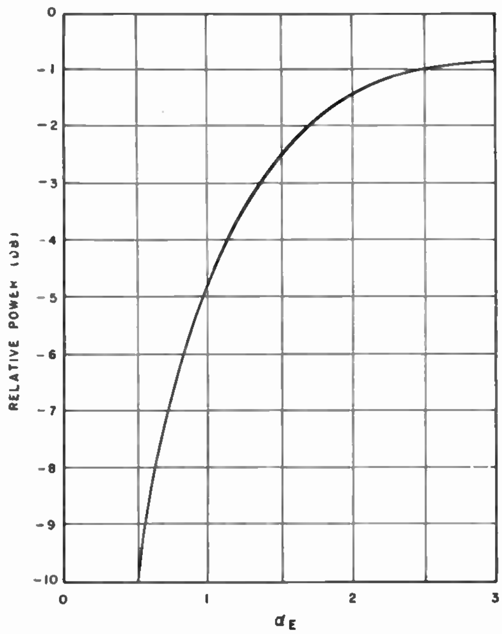


Fig. 5—Spillover for equal edge tapers in E and H-planes.

Both these components are shown in Fig. 6. It may be observed that there is a broad range in α about which near-optimum gain may be achieved.[5]

Remarks concerning the accuracy of (11) apply equally to (14). The maximum efficiency predicted by (14) is found to be 74 per cent, which may be compared with the efficiency of 65 per cent commonly used for paraboloid antennas. With regard to the substitution of α_m for α in the gain (14), it should be noted that the spillover effect on gain is independent of α_m, whereas the beam broadening is not. When the correction to α_m is due to mismatch, this energy loss may be added to the spillover loss and (14) may be entered with α_m.

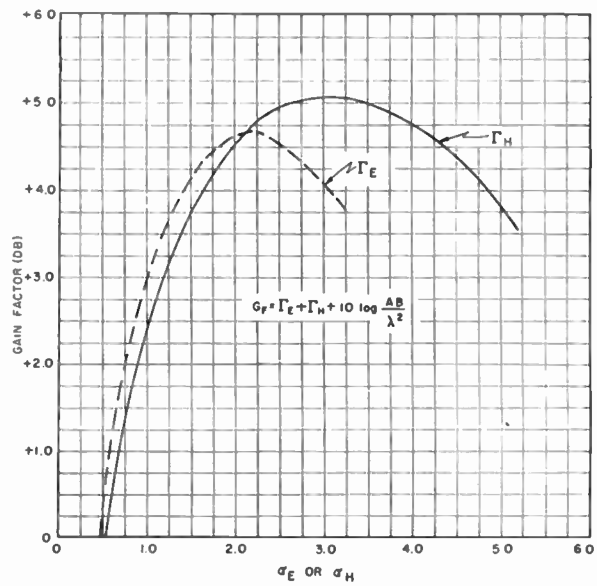


Fig. 6—Gain of antenna with rectangular aperture fed by a horn.

Conclusions

Radiation patterns of antennas fed by horns have been derived and related to the physical dimension of both primary and secondary antennas by means of an illumination factor, α. Cross referencing among the various pattern characteristics has been facilitated by the use of α as a parameter common to all important equations. While the use of the relationships directly in terms of α is applicable with little error to a wide class of practical antenna systems, it has been indicated how the applicability of the results may be further extended.

Acknowledgment

The author wishes to acknowledge the assistance of William Bales in the derivation of equations (14).

[5] J. Ruze, "Wide-angle metal plate optics," Proc. I.R.E., vol. 39, p. 697; June, 1951, shows curves for spillover and gain assuming cosine-squared horn patterns for both planes, and neglecting horn side lobes.

Information Cells on Intensity-Modulated CRT Screens*

DANIEL LEVINE†, MEMBER, IRE

Summary—**The distribution of current within the beam of a cathode-ray tube has a Gaussian variation. Consequently, if the wave form of a pulse of beam current is known, it is possible to determine the excitation of an intensity-modulated screen surface. In this report the nature of the excitation is discussed for an intensity-modulated sweep for both rectangular and triangular current waveforms. The results are extended to indicate what may be expected of an actual mapping radar set.**

The theoretical constants which arise in the development are evaluated from data obtained by the shrinking raster method of measuring spot size, which is termed line width in this paper for purposes of clarity. This permits determination of the size of an information cell on the screen as a function of pulse duration, sweep speed and line width. Then the number of information cells available on a tube may be determined. As a consequence, we find that there is no significant difference in the number of information cells available on the standard 5FP7, 7BP7, or 12DP7.

Furthermore, the reduction of the over-all receiving-system frequency response by some radar displays may be estimated. In such a case the video bandwidth may be reduced.

Rectangular Current Pulse

The distribution of electrons in the beam of a cr tube is closely approximated by a Gaussian curve. Consequently, the current distribution about the central point of a stationary beam is

$$i(x, y) = I_M e^{-k^2 r^2} = I_M e^{-k^2(x^2+y^2)} \tag{1}$$

where r is the radial distance from the center of the beam to the point (x, y).[1]

Now if the velocity, v, oriented along the x-axis, is applied to the electron beam, the instantaneous current is then

$$i(x, y) = I_M e^{-k^2[(x-vt)^2+y^2]}. \tag{2}$$

Then the total charge delivered to the point (x, y) when the beam current starts to flow at $(0, 0)$ at time $t=0$ and ends at time $t=\tau$ is

$$Q(x, y) = \int_0^\tau i(x, y, t)dt$$
$$\equiv \frac{I_M \tau e^{-k^2y^2}}{k\lambda} \frac{\sqrt{\pi}}{2} \{H(kx) - H[k(x - v\tau)]\}. \tag{3}$$

This function is plotted in the form

$$Q_r(x, \lambda) = \frac{k\lambda Q(x, y)}{\sqrt{\pi}\, \tau I_M e^{-k^2y^2}}$$
$$= \frac{1}{2} \{H(kx) - H[k(x - \lambda)]\} \tag{4}$$

in Fig. 1.[2] The maximum value of unity is approximated at some point of all these curves so long as

$$k\lambda < 4. \tag{5}$$

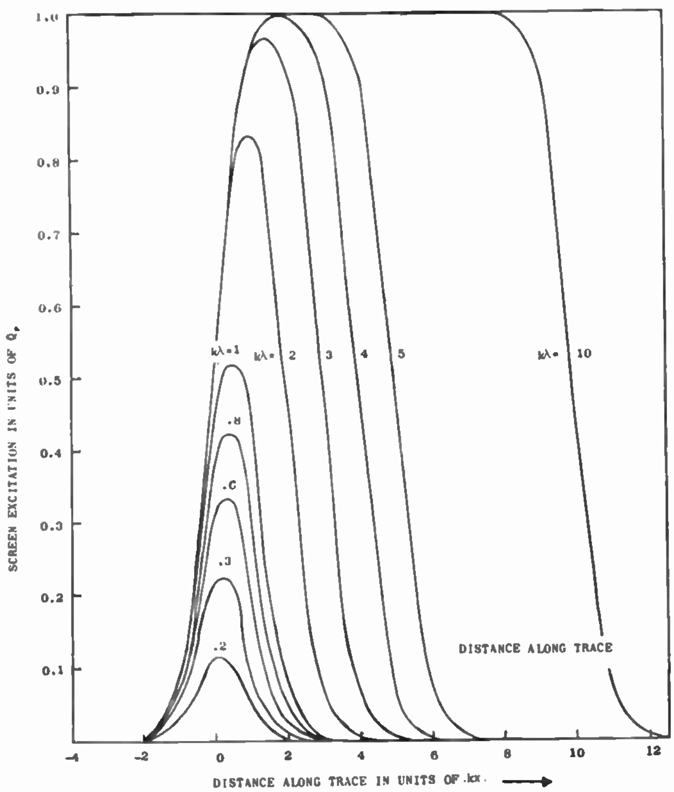


Fig. 1—Screen excitation for rectangular current pulses of length $k\lambda$.

In the shrinking raster method of measuring spot size,[3] sweep lines are of uniform brightness, being of the form we would expect for $k\lambda > 10$. Consequently, except for ends of a sweep line, $Q_r(x) = 1$, whence:

$$Q(x, y) = \frac{\tau\sqrt{\pi}}{k\lambda} e^{-k^2y^2}. \tag{6}$$

For a given beam current, the intensity at the edge of a line defined by this method is about 40% of

* Decimal classification: R537.131×R138.31. Original manuscript received by the Institute, Dec. 29, 1952; revised manuscript received, July 27, 1953. This report is condensed from a classified report of the same title; WADC Technical Report 53-90, May, 1952.

† Aircraft Radiation Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio.

[1] This section through (4) is a generalization of a paper prepared at the Admiralty Signal Establishment, entitled "Effect of pulse length on excitation of screen of an intensity modulated cathode ray tube," Rpt. No. Br-701/43; June 9, 1943.

[2] Fig. 1 is copied from footnote reference 1.

[3] T. Soller, M. A. Starr, and G. E. Valley, Jr., "Cathode Ray Tube Displays," McGraw-Hill Book Co., Inc., New York, N. Y.; pp. 594–597; 1948.

the peak intensity.[3] Furthermore, the current and intensity are related in a linear manner, provided that the current density is not so great as to cause current saturation of the phosphor.[4] Therefore, we conclude that total charge is proportional to the integral of the instantaneous intensity, the latter being the significant quantity to the viewing or recording mechanism.

Now the peak total charge obviously is at $y=0$, being given by

$$Q(x, 0) = \frac{\tau\sqrt{\pi}}{k\lambda}.$$

Consequently, at the edge of a line, where $y=w/2$,

$$\frac{0.4\tau\sqrt{\pi}}{k\lambda} = \frac{\tau\sqrt{\pi}}{k\lambda} e^{-k^2(w/2)^2},$$

whence:

$$k = \frac{1.9145}{w}. \tag{7}$$

Substitution into (1) yields

$$i(x, y) = I_M e^{-3.67(x^2+y^2)/w^2}. \tag{8}$$

Triangular Current Pulse

The shape of the pulse received from a point target which modulates the electron beam of the cr tube is dependent upon the shape of the transmitted pulse and distortion in the receiver. While many radar sets, requiring accurate ranges, have sufficiently wide receiver bandwidths to pass the transmitted pulse without distortion, other systems of the search type may have very narrow bandwidths, resulting in considerable distortion. As a consequence, it is necessary to consider additional pulse shapes. In general, a selected shape of pulse does not result in an integral for which the values are tabulated; consequently, we are constrained in our selection. For this reason the pulse shape which we next consider is triangular; the beam current is

$$i = \begin{cases} 0 & t \leqq 0 \\ \dfrac{2I_M}{\tau} t & 0 \leqq t \leqq \tau/2 \\ \dfrac{2I_M}{\tau}(\tau - t) & \tau/2 \leqq t \leqq \tau \\ 0 & \tau \leqq t. \end{cases} \tag{9}$$

The screen excitation is obtained upon duplicating the treatment of the rectangular pulse:

$$Q(x, y) = \frac{2I_M}{\tau} e^{-k^2y^2}\left\{\int_0^{\tau/2} te^{-k^2(x-vt)^2}dt + \int_{\tau/2}^{\tau} (\tau - t)e^{-k^2(x-vt)^2}dt\right\},$$

whence:

$$\begin{aligned} Q_t &= \frac{kvQ(x, y)}{\sqrt{\pi}\, I_M e^{-k^2y^2}} \\ &= \frac{1}{k\lambda}\Bigg\{kxH(kx) + k(\lambda - 2x)H\left[k\left(x - \frac{\lambda}{2}\right)\right] \\ &\quad + k(x - \lambda)H[k(x - \lambda)] \\ &\quad + \frac{1}{2}\left(H'(kx) - 2H'\left[k\left(x - \frac{\lambda}{2}\right)\right]\right. \\ &\quad \left. + H'[k(x - \lambda)]\right)\Bigg\}. \end{aligned} \tag{10}$$

This equation shows even symmetry about $kx = k\lambda/2$. It is plotted about the point of symmetry for several values of $k\lambda$ in Fig. 2 with the maximum value normalized to unity.

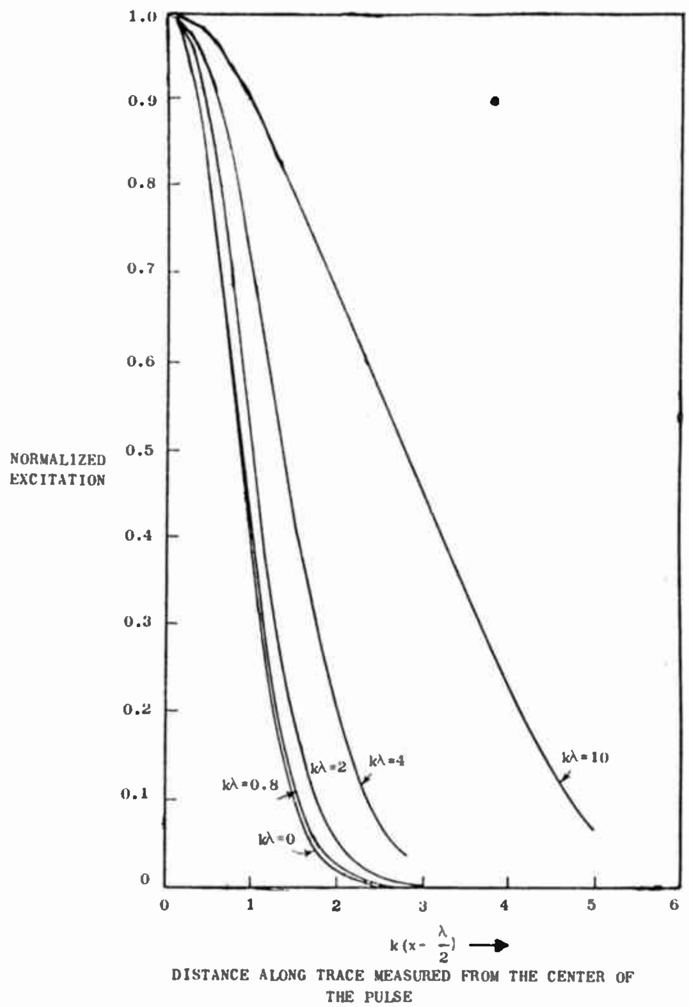


Fig. 2—Normalized screen excitation curves for triangular current pulses of length $k\lambda$.

Information Cells

Measurement of spot size by the shrinking raster method does not involve a determination of where the edges of a scanning line seem to disappear, but consists of noting when adjacent lines appear to merge. The results are, therefore, an indication of how closely

[4] G. Liebmann, "The image formation in cathode-ray tubes," Proc. I.R.E., vol. 34, pp. 580–586; Aug., 1946.

units of information may be placed on a phosphor, and still be resolved. Consequently, we shall assume that when two identical pulses are spaced radially on the tube so that the crossover of their charge distributions occurs at 40% of the peak intensity,[5] then the pulses are just resolvable as separate entities. The distance between the 40% points is defined as an *information cell.*

This definition admittedly is of an arbitrary nature, since we require identity of pulse shape and amplitude. It does, however, permit associating a unique number with each type of cr tube for a given radar pulse length and maximum beam current (since line width is a function of beam current).

For triangular current pulses, the 40% point corresponds to an ordinate of 0.4 in Fig. 2. The size of the information cell is then obtained by doubling the abscissa value at which each curve crosses this ordinate. The resulting function is plotted in Fig. 3, with another curve for rectangular pulses.

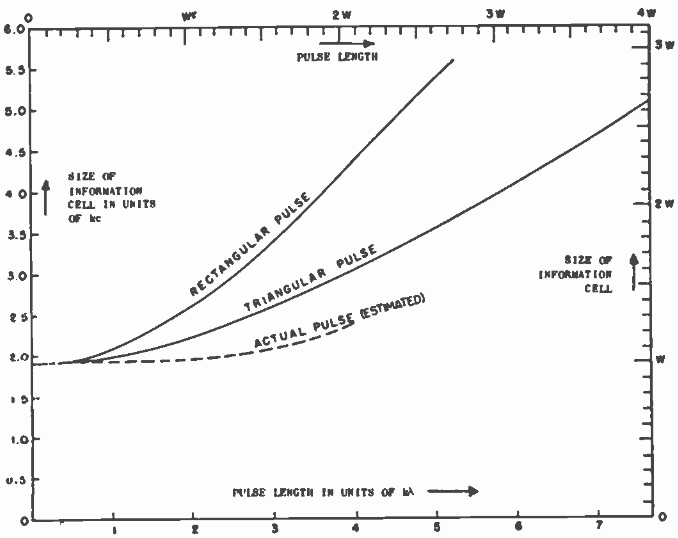


Fig. 3—Size of an information cell as a function of pulse length on the screen; w is the line width measured by the shrinking raster method; c is the size of an information cell; *pulse length* is equal to $v\tau$. The *rectangular pulse* curve is applicable to receivers having a large bandwidth-pulse length product; the *estimated* curve applies to receivers having a small value of this product.

A third dashed curve is sketched in to represent what may be expected of a typical mapping radar set.

[5] Resolution of two pulses probably occurs farther down than the 40% point which applies to lines; however, the correct curves can be drawn readily as soon as datum on the proper value is available.

This curve is based upon the assumption that as the voltage waveform deteriorates from rectangular to triangular to the actual case for a mapping radar system, the corresponding excitation curves (and size of information cells) fall off.

We have superimposed scales in units of line width, by the use of (7); these are more readily interpretable than the $k\lambda$ and kc scales. On the basis of the dashed curve we are able to say that so long as the pulse length on the cr tube is less than the line width, the number of information cells in a radius is constant. For the 5FP7, 7BP7, 9GP7, and 12DP7, tubes this constant is approximately 100 for a range setting of 15 nautical miles and pulse length of 3/8 microsecond.

The further significance of our development may be demonstrated by considering a radar system having a pulse length of one microsecond, a 50-mile range sweep, and display on the 5FP7; then

$$k\lambda = 1.96 \frac{D\tau}{wR} = 0.328.$$

Since the pulse length is one microsecond, a video bandwidth of 0.5 mc may be considered necessary to pass all information; however, the pulse length may be increased by a factor of 3 without materially affecting the number of cells, so that a much smaller bandwidth is adequate.

Symbols

- c Diameter of an information cell, mm.
- D Diameter of a cr tube, inches.
- $H(x) \equiv (2/\sqrt{\pi})\int_0^x e^{-\mu^2} d\mu$, the probability integral.
- I_M Beam current at the center of the electron beam.
- $Q_r(x)$ Charge distribution function for rectangular current pulses (4).
- $Q_t(x)$ Charge distribution function for triangular current pulses (10).
- R Radial sweep range on a cr tube, nm.
- v Beam velocity, mm/microsecond.
- w Line width measured by the shrinking raster method, mm.
- x Abscissa, directed along velocity vector of a moving beam.
- y Ordinate.
- λ Pulse length on the screen, mm.
- τ Pulse duration, microseconds.

Measurement of Resonant-Cavity Characteristics*

G. L. HALL† AND PHILIP PARZEN‡, SENIOR MEMBER, IRE

Summary—The circuit properties of a resonant cavity are effectively described by its loaded Q, unloaded Q, and shunt resistance. One method of Q measurement depends on an accurate knowledge of the variation of VSWR as a function of frequency in a transmission line terminated by the resonant cavity. A method of measuring shunt resistance along any path in the cavity entails accurate observation of the resonant-frequency shifts caused by an obstacle placed at points along the path. Therefore, both measurements require an AFC system with good stability and high resolution.

The parameters of a re-entrant cavity with apertures are considered and the associated experimental setup is described.

Introduction

The circuit properties of a microwave resonant cavity may be calculated quite accurately for simple geometries. However, the presence of coupling mechanisms, apertures in the wall, or other discontinuities complicates the calculations. Hence, resort is made to experimental measurement of parameters when a high degree of accuracy is desired for a practical cavity of arbitrary shape.

A knowledge of loaded Q, unloaded Q, and shunt resistance of the cavity, is necessary for a complete description of circuit properties. External Q and circuit efficiency are calculable from the first two parameters.

Description of the Cavity

The re-entrant resonant cavity under consideration and its coupling to a coaxial transmission line are illustrated in Fig. 1. The cavity was similar to those used in klystrons and in studies of electron beams or gas discharges. The shunt resistance of interest is that which is defined along the axis of the cavity. The cavity dimensions, other than those of the center hole, were scaled from one of Hansen's.[1] Proper consideration of the various scaling factors gave 3,600 for the unloaded Q and 2.46×10^5 ohms for the shunt resistance. The center hole along the axis symmetry should decrease the unloaded Q and raise the value of the shunt resistance.

A coaxial line with a coupling wedge as an integral part was fitted tightly into the cavity and clamped in position. The front face of the wedge was kept in the plane of the inner wall of the cavity by a stop. For any given angle of wedge, the coupling could be varied by rotating the coaxial line and wedge with respect to the cavity. Two positions for maximum coupling are shown in Fig. 2. The circuit efficiency at these two positions depended on the wedge angle; about 120 degrees gave approximately 50 per cent circuit efficiency, that is, critical coupling. Position A gave slightly higher values of resonant frequency and loaded Q than B.

Smaller wedge angles in the same positions afforded higher circuit efficiencies and lower Q's. Fig. 3 illustrates four positions of a 90 degrees wedge for critical coupling. Notice that critical coupling was not the maximum coupling obtainable with this wedge. Therefore, it was

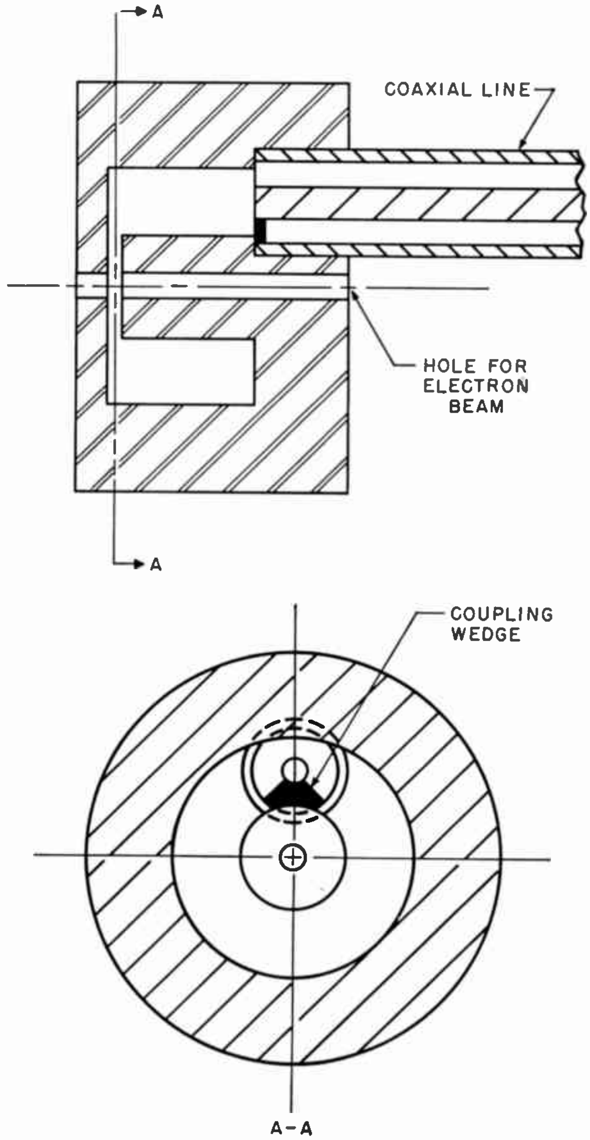


Fig. 1—Experimental test cavity.

* Decimal classification: R119.3. Original manuscript received by the Institute, October 24, 1952; revised manuscript received July 15, 1953. Presented, Conference on High-Frequency Measurements, Washington, D. C., January 14, 1953. This work sponsored by U. S. Army Signal Corps Eng. Labs., Fort Monmouth, N. J.

† Formerly Fed. Telecommun. Labs. (a division of IT & T Corp.), now at University of Virginia.

‡ Formerly Fed. Telecommun. Labs. (a division of IT & T Corp.), Nutley, N. J.

[1] D. R. Hamilton, J. K. Knipp, and J. B. H. Kuper, "Klystrons and Microwave Triodes," McGraw-Hill Book Co., Inc., New York, N. Y., p. 78; 1948.

possible to maintain a constant circuit efficiency, a desirable feature in measuring current modulation fluctuation in an electron beam passing through the cavity.

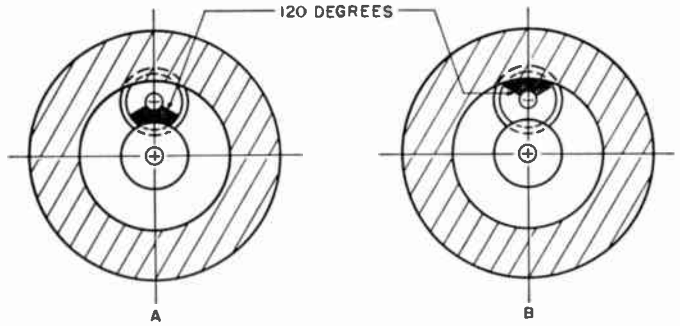


Fig. 2—Coupling positions for large wedge angles.

Thus, the measured band-width of the fluctuations may be varied without impairing circuit efficiency, and yet vary values of the various Q's. Also, for large wedge angles, unloaded Q changed little when the coaxial line and wedge were rotated to change circuit efficiency.

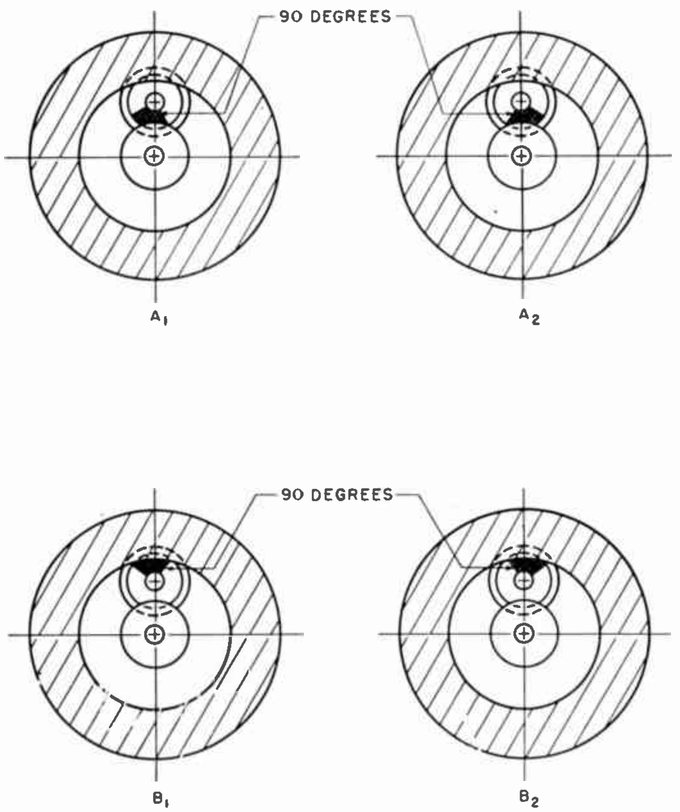


Fig. 3—Coupling positions for small wedge angles.

The Q measurements to be discussed were made with a wedge angle of 118 degrees in position A_1.

Q Measurement

The various Q's may be defined with the aid of the following equations. When a power P is excited in the cavity, a part P_0 is lost in the walls of the cavity, and the remaining part P_L is delivered to the load. Then

$$\text{unloaded } Q \text{ or } Q_0 = \omega_0 W/P_0,$$
$$\text{external } Q \text{ or } Q_e = \omega_0 W/P_L,$$
$$\text{loaded } Q \text{ or } Q_L = \omega_0 W/P.$$

Q was measured by terminating a transmission line with the cavity and measuring the VSWR and the position of the minimum as a function of frequency. The half-power points $r_{1,2}$ were determined from

$$r_{1,2} = \frac{1 + r_0 + [1 + (r_0)^2]^{1/2}}{1 + r_0 - [1 + (r_0)^2]^{1/2}}$$

where r_0 equals the VSWR at resonance. For the loaded Q, $Q_L = f_0/\Delta f$.

A plot of the position of the minimum VSWR versus frequency was used to identify undercoupling or overcoupling. Fig. 4 illustrates a typical Q measurement.

Emphasis was placed on stability of frequency during measurements of VSWR. Fig. 4 illustrates the small increments of frequency that were possible with the use of an AFC system.

The method of measurement neglects the series losses in the coupling between the cavity and transmission line. The VSWR far from resonance is a measure of these losses: a low ratio corresponds to high losses. The VSWR curve in Fig. 4 was plotted up to a ratio of 40 without approaching a finite asymptotic value. Then at a point very far from resonance, the VSWR was found to be greater than 178, which was the highest value measurable with the calibrated attenuator. Therefore, the series losses were negligible.

Shunt-Resistance Measurement

The shunt resistance R over a path will be defined as

$$R = \frac{(\int E ds)^2}{P_0}.$$

The integral is the line integral of the rms field over the desired path, which in our case is along the axis of symmetry of the cavity. Rewriting the equation for the unloaded Q

$$P_0 = \frac{\omega_0 W}{Q_0},$$

then

$$\frac{R}{Q_0} = \frac{(\int E ds)^2}{\omega_0 W}.$$

The electric- and magnetic-field distributions in the cavity are not known; therefore, R/Q_0 is not immediately calculable. However, indirect measurements of field distribution were described by Hansen and Post,[2] Maier,[3]

[2] W. W. Hansen and R. F. Post, "On the measurement of cavity impedance," *Jour. Appl. Phys.*, vol. 19, p. 1059; November, 1948.

[3] L. C. Maier, "Field Strength Measurements in Resonant Cavities," Tech. Rep. 143, Research Lab. of Electronics, MIT; November 2, 1949.

and Casimir.[4] The method consists of observing the shift in resonant frequency of the cavity caused by inserting small conducting obstacles. The shift depends on the strength of the fields at the obstacle.

For obstacles whose dimensions are small compared to the wavelength, the frequency shift $\Delta\omega$ as given by Casimir is

$$-\frac{\Delta\omega}{\omega_0} = \frac{H \cdot M + E \cdot P}{2W},$$

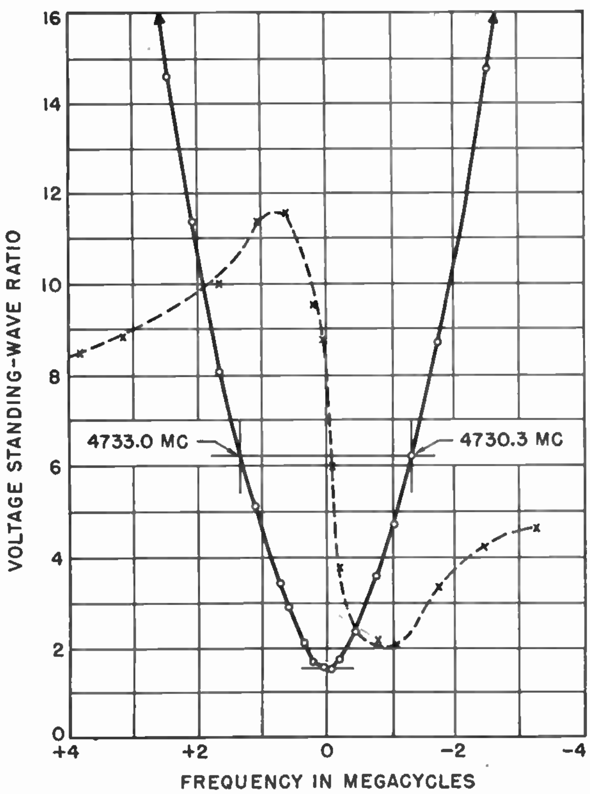


Fig. 4—Typical Q curve. $f_0 = 4731.6$ mc, $\Delta f = 2.7$ mc, and $Q_L = 1.75 \times 10^3$. The frequencies are given for the half-power points. The voltage standing-wave curve (dashed) has been drawn to an arbitrary scale.

where E and H are the electric and magnetic fields, respectively, at the obstacle and P and M are the total rms electric and magnetic moments of the obstacle. The quantities P and M may be computed by static considerations, since the dimension of the obstacle is small in comparison with the wavelength.

For a small metallic sphere of radius b

$$P = 4\pi\epsilon_0 b^3 E,$$

$$M = -2\pi\mu_0 b^3 H,$$

$$-\frac{\Delta\omega}{\omega_0} = \frac{-2\pi\mu_0 b^3 H^2 + 4\pi\epsilon_0 b^3 E^2}{2W}.$$

[4] H. B. G. Casimir, "On the theory of electromagnetic waves in resonant cavities," *Philips Res. Rep.*, vol. 6, pp. 162–182; June, 1951.

Assuming $H=0$ along the axis of symmetry of the resonant cavity herein, the frequency shift for a metallic sphere is

$$-\frac{\Delta\omega}{\omega_0} = \frac{4\pi\epsilon_0 b^3 E^2}{2W}.$$

Then

$$R/Q_0 = \frac{-1}{2\pi\omega_0 b^3}\left[\int \left(\frac{\Delta\omega}{\omega_0}\right)^{1/2} ds\right]^2.$$

Therefore, a plot of $(\Delta\omega/\omega_0)^{1/2}$ versus position of the obstacle has to be measured experimentally and integrated to obtain R.

Measurement of Resonant-Frequency Shift

Microwave power from a stabilized klystron was fed into the E-arm of a matched magic tee. The test cavity terminated one of the side arms and an adjustable short was in the other side arm. Power in the H-arm was monitored with a crystal detector. The adjustable short was tuned for minimum crystal current with the klystron oscillator frequency far from the resonant frequency of the test cavity. Next, the klystron, which was stabilized by an AFC system, was tuned to the resonant frequency of the test cavity. Resonance was indicated by a dip in crystal output. The value of the resonant frequency of the test cavity was determined with a wavemeter that has a loaded Q of 7,000.

After determining its undisturbed resonant frequency, the cavity was perturbed by the introduction of a small spherical conductor and the new resonant frequency was measured to obtain the shift in frequency.

Spherical obstacles with radii as small as 0.0156 inch were used with resulting maximum frequency shifts in the order of 5 mc. Some difficulty was encountered in suspending such a small obstacle in the cavity. Maier could use larger spheres because of the longer wavelength of his cavities. He detected no effects from a silk thread on which obstacles were suspended. In the present experiments, however, the effects of a thread were noticeable. The best results were achieved by cementing the sphere with polystyrene Q dope to a small taut nylon thread. The thread passed through the cavity and was kept taut by weighting its end.

Fig. 5 gives frequency changes as a function of the position of the center of the spherical obstacle along the axis of the test cavity. The solid curve represents the frequency shift induced by the sphere, thread, and cement; the dashed curve shows the effects of the cement and thread; and the graph base line represents the resonant frequency of the unperturbed cavity. Since the resonant-frequency shifts induced by the thread and cement are small in proportion to the total frequency shift, it seems justifiable to subtract the two perturbations to obtain the amount of shift $\Delta\omega$ caused by the sphere alone.

In this manner, data for a curve of $(\Delta\omega/\omega_0)^{1/2}$ versus obstacle position were obtained. A planimeter was used to determine the area of the curve. The resulting value of R was 8.33×10^5 ohms. This was higher than expected by a factor 3.39, and indicates that the electric field along the axis of the cavity was changed appreciably by the introduction of a hole in the immediate vicinity.

The method of measuring resonant-frequency shifts was checked at one position of the obstacle in the following manner. With the obstacle in the cavity at the position of greatest frequency shift, the resonant frequency was also obtained from a Q measurement, as shown in Fig. 4. The result agreed with that obtained previously.

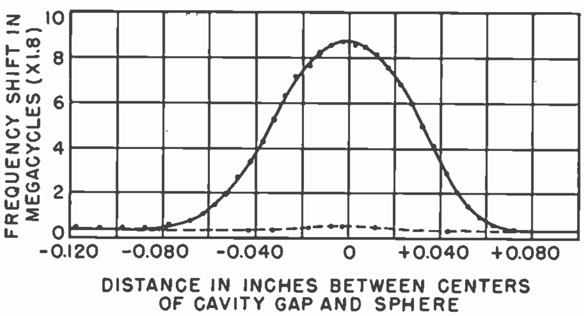


Fig. 5—Resonant-frequency shifts introduced by a 0.0156-inch-radius (or 0.0312-inch-diameter) steel sphere suspended in the cavity. The frequency shifts caused by the nylon thread and Q dope that supported the sphere is given by the dashed line. The zero frequencies (sphere in center or suspension only) were 4726.7 mc and 4731.6 mc, respectively.

Measurements of frequency shifts were taken using 0.040-inch- and 0.062-inch-diameter spheres. The 0.040-inch-sphere results checked with those for a 0.0312-inch sphere. However, the 0.062-inch sphere gave greater frequency shifts than would be expected from $\Delta\omega/\omega_0$, which is proportional to b^3. It was concluded that the largest sphere caused too great a perturbation.

It is pertinent to mention that the measurements of both loaded and unloaded Q's and of shunt resistance R were possible only by the use of a stabilized klystron oscillator.

Fig. 6 gives a block diagram of the AFC system. The klystron output was sampled by means of a 30 db directional coupler to the H-arm of a magic tee. The two side arms of the magic tee contained an adjustable short and a reference cavity, respectively. After the proper positioning of the adjustable short, the difference between the reflections from the two side arms was detected by the crystal in the E-arm.

The characteristics of the magic tee were utilized as follows. The output of a 5 kc audio oscillator was fed into a variable phase-shifting network. The two outputs had variable relative phase. One of the two was used to drive a power amplifier for a headphone. The headphone diaphragm was built into and formed a part of the wall of the reference cavity. There resulted a 5 kc modulation of the resonant frequency of the reference cavity about its original resonant frequency, which was called the center frequency of the reference cavity.

If the klystron were oscillating at the center frequency of the reference cavity, there would be a minimum crystal output. However, if the klystron drifted off the resonant frequency of the reference cavity, the crystal output increased and the phase of the crystal output was determined by the direction of the frequency shift of the klystron.

The crystal output from the E-arm of the magic tee was amplified and used to unbalance a balanced detector that was driven by the second output from the phase shifter. The variable phase shifter had to be adjusted so that there was no discriminator output when the klystron was oscillating at the center frequency of the reference cavity, and the correct polarity had to be observed when connecting the discriminator output in series with the repeller supply.

To check its performance, the AFC system was carefully aligned and a wavemeter with a loaded Q of 7,000 was tuned to the resonant frequency of the klystron. No appreciable correcton voltage was being provided; the repeller supply voltage was -180 v. The repeller supply was then changed to -300 v; the AFC system restored it to the original value and the resonant frequency of the klystron did not change. Next, with the repeller supply set at -300 v, the repeller supply switch was turned on and off alternately; there was no detectable motion of the needle of the dc meter of the wavemeter. That it to say, during these rapid changes in the repeller supply voltage, the klystron remained stable within the resolution of a wavemeter of 7,000 loaded Q. When the experiment was repeated with the wavemeter tuned to the steep side of its resonance characteristic, only a slight movement of the indicator needle occurred.

The wavemeter was detuned from the frequency of the stabilized klystron until its dc indication had decreased to one-half of the smallest scale division; this corresponded to a frequency change of 240 kc. It was estimated that one-fourth of this change could have been observed; that is, a 60 kc frequency change in the klystron oscillator would have resulted in a detectable motion of the wavemeter indicator. Therefore, it seems justifiable to say that the AFC system had a resolution of at least 100 kc. The stability was believed to be better than 10 kc, but the backlash in the micrometer head of the wavemeter prevented a more accurate and definite determination.

A second test of stability concerned the effects of temperature variations in the klystron. The AFC system was set up and left on for 6 hours without any forced cooling of the klystron. After the frequency was measured, two constant-speed blowers were applied to the hot klystron. Thirty minutes of cooling by the blowers produced no detectable change in frequency.

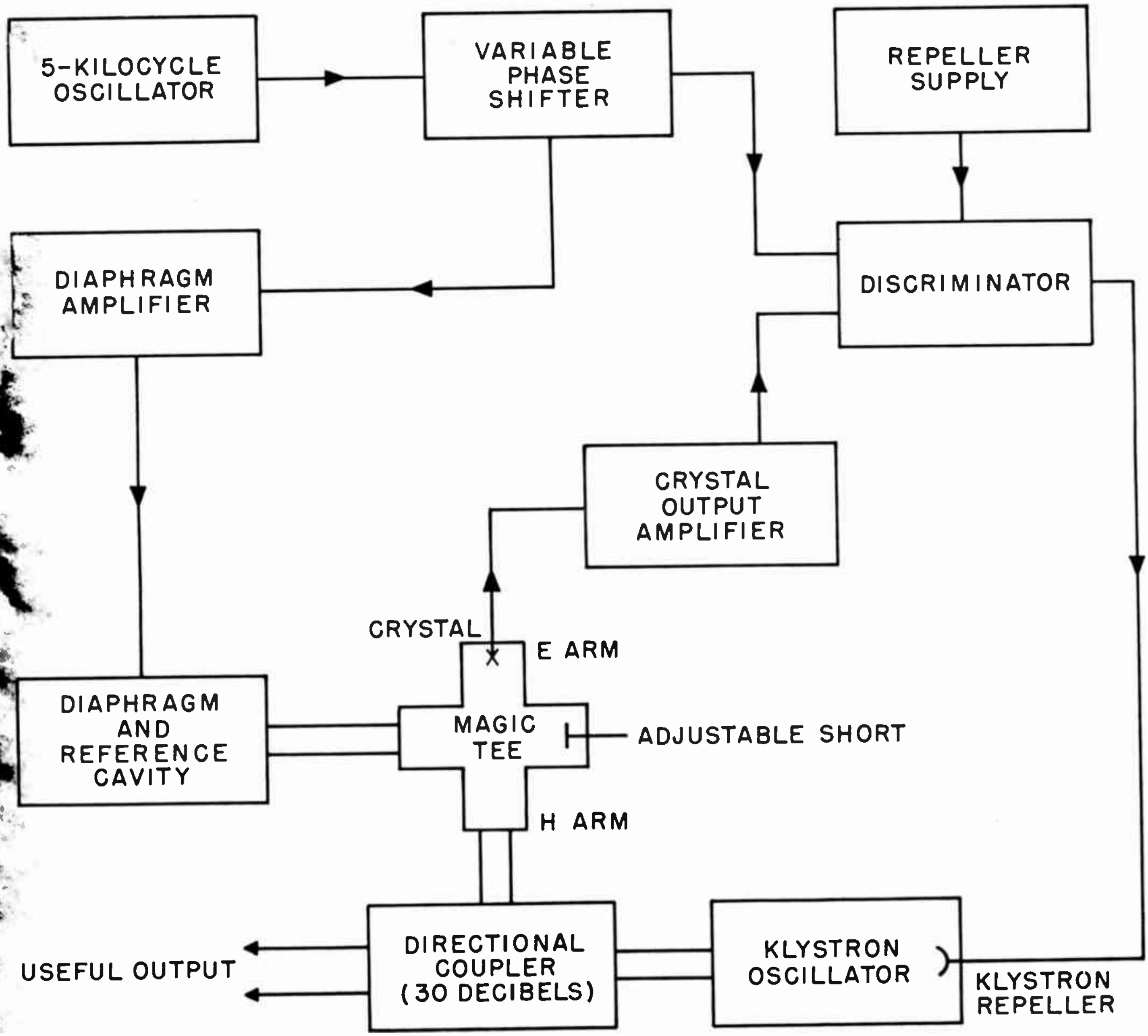


Fig. 6—Block diagram of AFC system.

Conclusion

A method has been described for measuring with great accuracy both the loaded and unloaded Q's and shunt resistance of a resonant cavity. This procedure entails precise measurements of frequency shifts caused by a small obstacle placed along a given path.

The degree of precision of this method is verified by the symmetry of the Q curves, which can be attained only by maintaining a high resolution in frequency. Moreover, because of this exacting frequency resolution, it has been possible in the measurement of shunt resistance to correct for perturbations of the string and cement supporting an obstacle in the cavity. This setup can be used where a source of stability is required.

Acknowledgment

The AFC system was designed and constructed by Mr. Harold Seidel. Some revisions were made during this work to improve its performance.

Evaluation of Polarization Diversity Performance*

JOHN L. GLASER†, SENIOR MEMBER, IRE, AND LAWRENCE P. FABER, JR.‡

Summary—**The performance realizable from the statistical relationship between the fading of signals received on vertically and horizontally polarized antennas has been evaluated by interpretation of the joint distribution of these signals. A brief description is given of special instrumentation which determined the joint distribution as the signals were received.**

Data were collected at 6.985 and 11.66 megacycles using unmodulated signals transmitted from Red Bank, N. J., and received near St. Louis, Mo. The performance at 11.66 megacycles was very nearly that expected of independent Rayleigh-distributed fading of the vertical and horizontal components of the received signals. At 6.985 megacycles the realizable diversity performance was somewhat less effective than would have been expected with independent fading.

INTRODUCTION

IT IS KNOWN that ionospherically propagated radio signals received on two antennas of different polarizations exhibit random variations in amplitude which appear to be statistically independent. This fact has been utilized to improve radio system reliability through the use of polarization diversity reception. This paper describes some measurements of the joint distribution of signal amplitudes received on antennas responding to vertical and horizontal polarization components of ionospherically propagated signals. The experimentally determined distributions are interpreted to show the improvement which is realizable from polarization diversity.

It is well known the distribution of signal amplitude developed in a single antenna by sky-wave signals closely approximates the Rayleigh distribution. Accordingly, the probability that the received signal amplitude E is at any instant less than some specified value E' is given by

$$\text{probability that } E < E' = 1 - e^{-0.693(E'/E_M)^2}, \quad (1)$$

where E_M is the median signal amplitude which is the amplitude exceeded one half of the time.

In narrow-band communication systems which are not affected by the frequency-selective aspects of fading, the signal will be unusable whenever the RF signal-to-noise ratio falls below a certain value. In such systems a least usable amplitude is determined by the least RF signal-to-noise ratio which can be tolerated and the total RF noise power consisting of set noise and noise received by the antenna. If E_L is the least usable signal amplitude, the fraction of the time that the si[gnal] is unusable is

$$\text{fraction of unusable time} = 1 - e^{-0.693(E_L/E_M}$$

This equation considers only the effects of [short-]period fading during times when E_L and E_M [are] considered constant. There are, of course, diurn[al, sea]sonal and random variations in both E_L and E_M [which] must be taken into account in determining th[e long-]term reliability of a radio system. Since the adva[ntages] of diversity reception are derived from the fav[orable] *short-term* statistics of signals received by two or [more] antennas, we shall regard E_L and E_M as constant p[aram]eters and compare diversity and non-diversity [per]formance for various combinations of these param[eters].

The statistical relationship between the fading [of] signals E_1 and E_2 received by the two antennas [of a] polarization diversity system can be described b[y the] joint distribution of these quantities. In a ma[nner] analogous to (1), we could determine the proba[bility] that E_1 at any instant will be less than some arbi[trary] value E_1' while E_2 is at the same time less than s[ome] arbitrary value E_2'. This cumulative joint distribu[tion] would be expressed as some function of E_1' and [E_2'] just as in (1) the cumulative distribution of E w[as a] function of E'.

This joint distribution of E_1 and E_2 would be affe[cted] by changes in the median values of the fading sig[nals] E_1 and E_2 which might result, for example, fr[om] changes in ionospheric absorption. The joint distri[bu]tion could be expressed as a function of E_1'/E_{M1} a[nd] E_2'/E_{M2}, where E_{M1} and E_{M2} are the median values [of] E_1 and E_2. Assuming that the factors which cause su[ch] changes in the median signal amplitudes do not aff[ect] the short-term fading distribution about the median, the distribution in this form would describe the st[a]tistics of the short-term fading without restriction [to] particular values of E_{M1} and E_{M2}. Thus the joint dis[]tribution could be expressed as

$$\left.\begin{array}{l}\text{probability that } E_1 < E_1' \\ \text{and } E_2 < E_2' \text{ simultaneously}\end{array}\right\} = P(E_1'/E_{M1}, E_2'/E_{M2}) \quad (3)$$

where P is some function which is to be determined.[1]

In a diversity receiving system, the fraction of un[]usable time is the fraction of the time that neither chan[]nel receives a signal whose amplitude exceeds the leas[t] usable amplitude. If E_{L1} and E_{L2} are the least usable amplitudes for the respective channels, the fraction of

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† Formerly Washington University, St. Louis, Mo.; now with Bell Telephone Laboratories, Inc., New York, N. Y.

‡ Formerly Washington University, St. Louis, Mo.; now with Vickers Electric Division, Vickers, Inc., St. Louis, Mo.

[1] For the case where E_1 and E_2 fade independently with Rayleigh distributions, $P = [1 - e^{-0.693(E_1'/E_{M1})^2}][1 - e^{-0.693(E_2'/E_{M2})^2}]$. Although some of the experiments showed this to be approximately true, there appears to be no *a priori* basis for assuming independent fading in the polarization diversity system.

unusable time is given by

$$\text{fraction of unusable time} = P(E_{L1}/E_{M1},\ E_{L2}/E_{M2}), \quad (4)$$

where the function P is the same as that defined by (3).

We have intentionally allowed for the possibility that $E_{L1} \neq E_{L2}$ and $E_{M1} \neq E_{M2}$. Usually the antennas of different polarization will also have different directivity characteristics and therefore it is possible that $E_{M1} \neq E_{M2}$. Also if E_{L1} and E_{L2} are established by noise and other interference received by the antennas (which is usually the case in the frequency range of interest here), it is possible that $E_{L1} \neq E_{L2}$ as a result of the different directivity characteristics of the two antennas.

We shall shortly describe some measurements in which functions of the type represented in (3) and (4) were determined experimentally. As is often the case with empirical data, the results of these experiments are most conveniently represented graphically. Since the fraction of unusable time is a function of two variables E_{L1}/E_{M1} and $E_{L2}/_{M2}$, such a graphical presentation is in the form of a surface, an example of which is illustrated in Fig. 1. It is obvious that drawings of the type shown in Fig. 1 are not simple to draw nor is it convenient to read data from such a drawing. Therefore surfaces of this type were usually depicted by contour maps on which curves representing various fractions of unusable time were plotted on the $(E_{L1}/E_{M1}, E_{L2}/E_{M2})$ plane. Fig. 1 has been presented here to illustrate the general form typical of the function $P(E_{L1}/E_{M1}, E_{L2}/E_{M2})$.

Instrumentation

The determination of the joint distribution of the two polarization components of the incident signals was aided considerably by the instrument system represented schematically in Fig. 2. Horizontal and vertical dipole antennas were connected to two receivers whose second-detector output voltages controlled the selector switches shown in the units labelled "level selector." One of the counters in the array shown in Fig. 2 was advanced every one-fifth second. The row in which a counter was advanced was determined by the amplitude of the signal from the horizontal antenna, while the column in which a counter was advanced was determined by the signal from the vertical antenna. Counter power was applied during times when the contacts of the sampling relays were open and the informa-

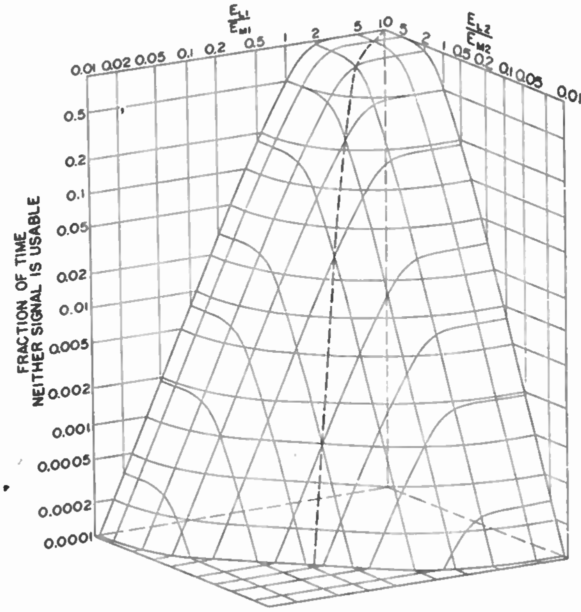

Fig. 1—An example of the joint distribution of signal amplitudes received by a vertical and horizontal dipole antenna interpreted to show the fraction of unusable time for various ratios of the median signal amplitudes to the least usable signal amplitudes. The dashed curve drawn on the surface shows the diversity performance when these ratios are equal for the two channels.

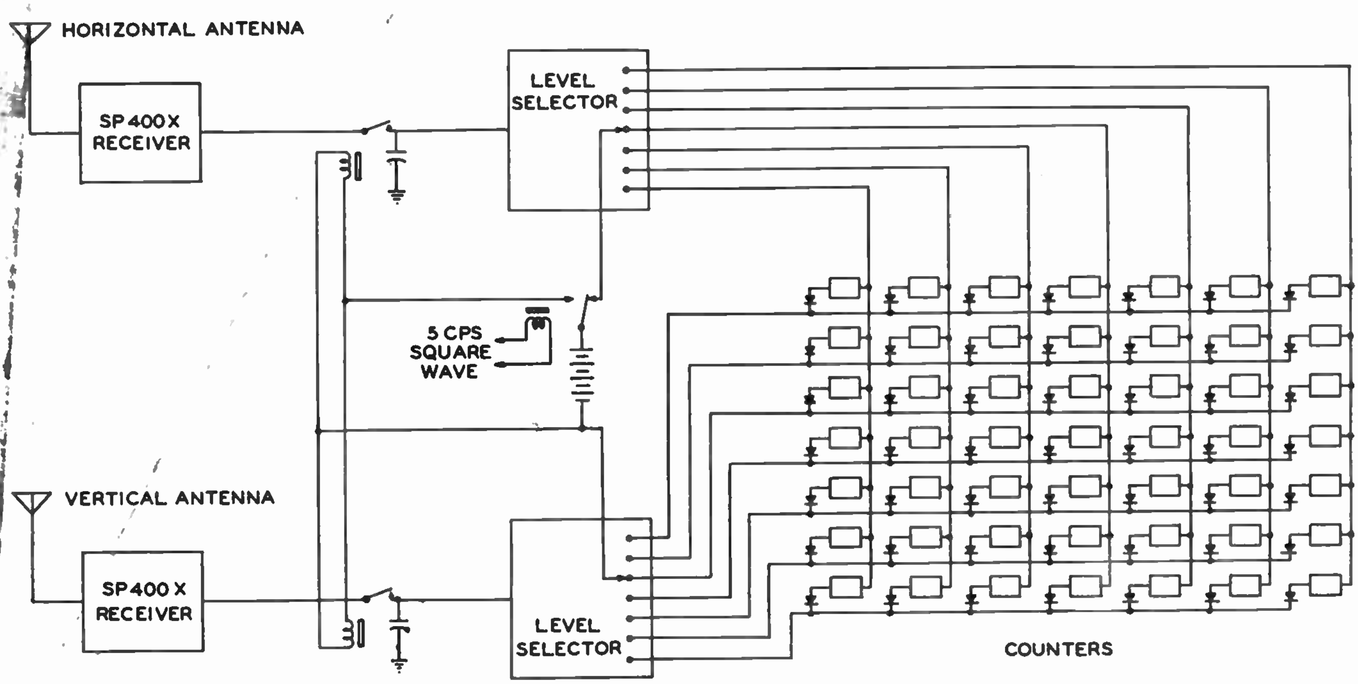

Fig. 2—Simplified diagram of the instrument system.

tion regarding the input signal amplitudes was stored at these times in terms of voltages across the two capacitors shown in Fig. 2. Thus each count represented simultaneous samples of the horizontal and vertical signal amplitudes taken at times when the sampling relay contacts opened. Since the sampling rate of five samples per second bore no fixed relationship to the random variations in signal amplitude, the requirement of random sampling was fulfilled.

The accumulation of counts on the various counters indicated the joint distribution of the signals received by the two antennas. This joint distribution also contains information regarding the individual or marginal distributions of the signal amplitudes received by each of the antennas. For example, the total number of counts accumulated in each column showed the number of samples for which the horizontal signal amplitude was found to be within the interval of signal amplitude represented by that column. This gave the marginal distribution for the horizontal signal. Similar totals for each row gave the vertical marginal distribution.

The marginal distributions indicated the non-diversity performance that would have been obtained with either of the two channels operating alone. These distributions also indicated the median amplitudes for each channel and this information was used to plot the joint distribution with signal amplitudes expressed relative to the median amplitudes. With this technique it was not necessary to know the actual gains of the two antennas and of the two receivers, although it was required that these gains remain fixed during each experimental run.

Comparison of Diversity and Non-Diversity Performance

It is often desirable to compare the performance of a diversity receiving system with a single-channel non-diversity system to determine whether the reduction in unusable time justifies the greater cost of the diversity system. For a particular fraction of unusable time, such a comparison reveals what relaxation of transmitter power requirement is permitted because of the use of diversity reception. This "diversity gain" provides a basis for attaching an economic value to the improvement obtained with diversity reception.

In a dual diversity system in which E_{M1}/E_{L1} and E_{M2}/E_{L2} are unequal for a given median incident field intensity and a given atmospheric noise level, the fraction of unusable time with each of the two channels operating separately as a non-diversity system will be different. It seems logical to compare the diversity performance with the non-diversity performance of the better of the two channels. When the diversity improvement relative to the better of the two possible non-diversity channels is considered for various ratios of E_{M1}/E_{L1} to E_{M2}/E_{L2}, it is found that the greatest diversity improvement occurs when the ratio of E_{M1}/E_{L1} to E_{M2}/E_{L2} is equal to 1.

This fact is illustrated in Fig. 3 which is drawn for the case where the fadings of the signals in the two channels are independently Rayleigh distributed. In this figure it is assumed that channel 1 is the better of the two channels, i.e. $E_{M1}/E_{L1} \geqq E_{M2}/E_{L2}$. The non-diversity curve shows the fraction of unusable time experienced by channel 1 alone and the various diversity curves indicate the fraction of unusable time for the diversity system for various ratios of E_{M1}/E_{L1} to E_{M2}/E_{L2}. When this ratio is less than 1, channel 2 becomes the better channel and the reference for evaluating diversity improvement. Performance curves corresponding to those in Fig. 3 for this case would be identical to those in Fig. 3 except that the subscripts "1" and "2" would be interchanged.

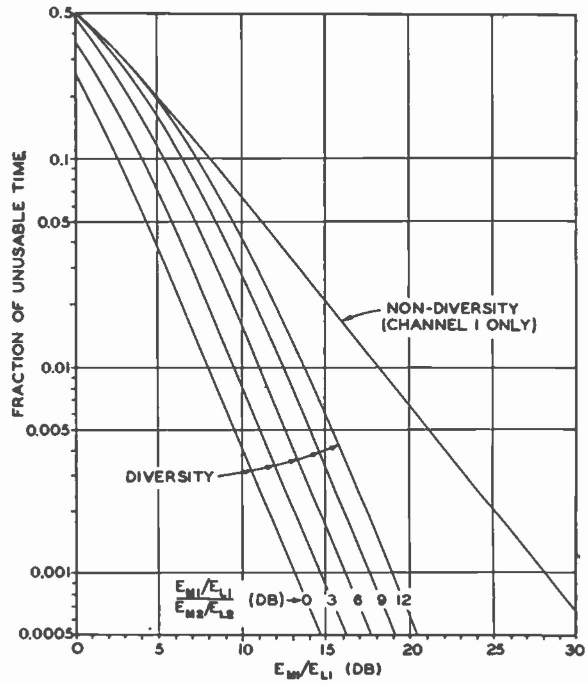

Fig. 3—Diversity and non-diversity performance when the signals received by the two antennas fade independently with Rayleigh distributions. Channel 1 is assumed to represent the better of the two channels, i.e., that with the larger ratio of median signal amplitude to least usable amplitude. The several diversity curves show the effect of various ratios E_{M2}/E_{L2} on diversity performance.

The diversity performance obtained when E_{M1}/E_{L1} and E_{M2}/E_{L2} are equal can be interpreted as indicative of the performance inherently attainable from the statistical relationship of the fading of the signals received by antennas of different polarization. It appears that this performance represents a proper basis for evaluating the capabilities of polarization diversity in comparison to other diversity techniques.

On the surface depicted in Fig. 1 the performance when the two ratios of median to least usable signal amplitudes are equal is represented by points along the dashed curve drawn on this surface. The ordinates to such curves obtained from a number of test runs on two operating frequencies were averaged to show the average performance attainable from polarization diversity.

Experimental Results

The average performance at two different frequencies on the path from Red Bank, N. J. to St. Louis, Mo. are shown in Figs. 4 and 5. The findings presented in Fig. 4 were obtained during daylight hours at a frequency of 11.66 megacycles. This frequency represented a typical frequency for daylight operation on this path. The non-diversity performance with the horizontal and the vertical antennas are shown separately in Fig. 4. It can be seen that the individual distributions of signal amplitude received by the two antennas did not differ appreciably.

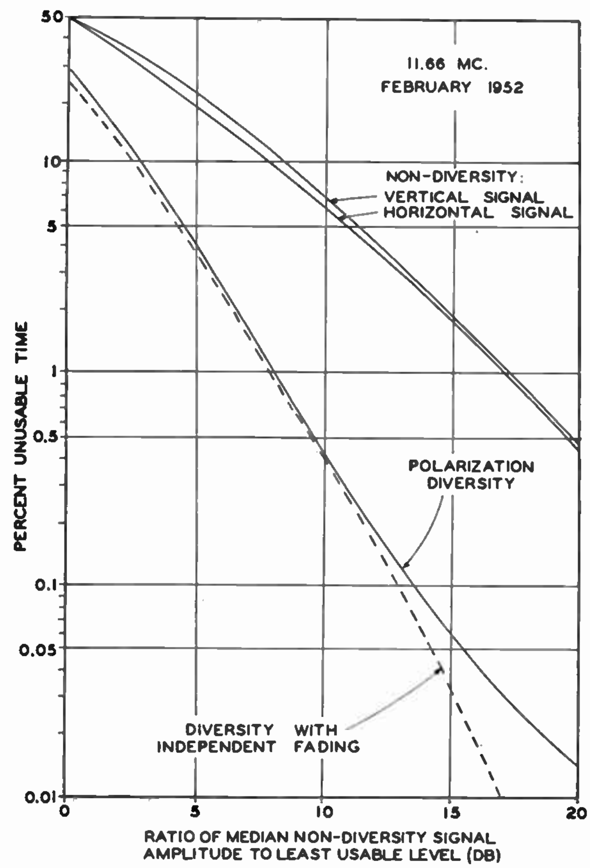

Fig. 4—Average polarization diversity performance when $E_{M1}/E_{L1} = E_{M2}/E_{L2}$, 11.66 mc, Red Bank, N. J. to St. Louis, Mo., February, 1952.

Also shown in Fig. 4 is the diversity performance which would have been indicated if the distributions represented by the two non-diversity curves had been independent. This figure shows that the actual diversity performance was only slightly less effective in reducing the fraction of unusable time than it would have been if the fading of the horizontal and vertical components of the received signal had been independent.

The results obtained at 6.985 megacycles on the same path are shown in Fig. 5. This frequency was a typical choice for night operation on this path and the data shown in Fig. 5 were obtained at night. Polarization diversity performance at this frequency was found to be somewhat less effective than at the higher frequency of 11.66 megacycles. The experiments at 6.985 megacycles also revealed a greater difference between the distributions of the horizontal and vertical components than was found at the higher frequency.

The difference in polarization diversity behavior at these two frequencies is in agreement with earlier observations based on a study of the distribution of the output signal from receivers actually connected as a diversity receiving system.[2] It was found in these experiments that polarization diversity performance improved as the operating frequency was increased. Spaced-antenna diversity, in contrast, showed poorer performance for a given physical separation of antennas as the operating frequency was increased.

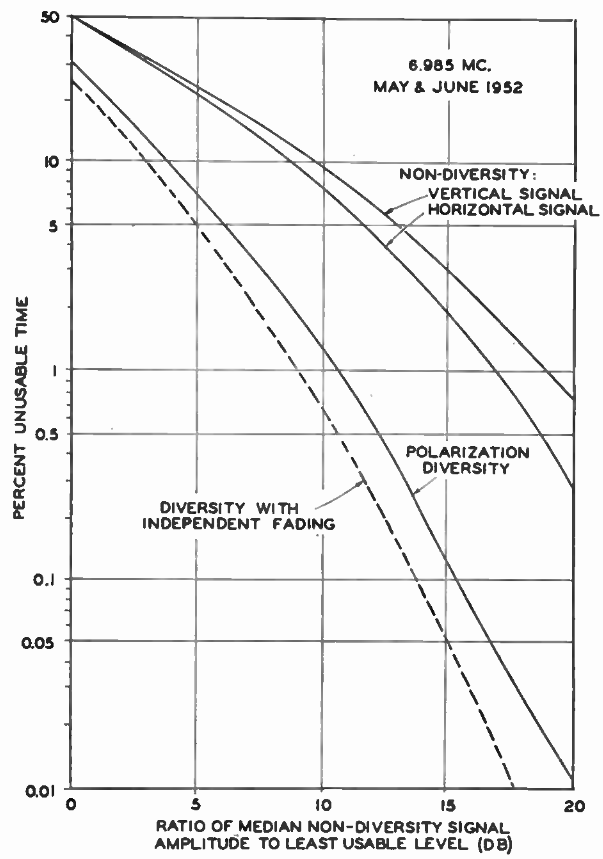

Fig. 5—Average polarization diversity performance when $E_{M1}/E_{L} = E_{M2}/E_{L2}$, 6.985 mc, Red Bank, N. J. to St. Louis, Mo., May and June, 1952.

Conclusions

Each of the series of experiments from which the data in Figs. 4 and 5 were obtained represented about fifty hours of actual recording time distributed over periods of about one month. While considerably more observations would be required to establish these findings as typical of polarization diversity performance, the results of these experiments are indicative of what can be obtained with this diversity method.

[2] Some of these observations were presented in a paper by S. H. Van Wambeck and A. H. Ross, "Performance of diversity receiving systems," Proc. I.R.E., vol. 39, pp. 256–264; March, 1951. Further observations were reported in a final report dated Aug. 31, 1952, submitted to the Signal Corps Engineering Laboratories under contract DA 36-039 sc-15331.

The analysis of the polarization diversity problem which led to the method of evaluation described here has pointed out a factor which influences the performance of actual polarization diversity systems. Although the fading of the vertical and horizontal polarization components of the received signals may approach statistical independence, this independence is not fully exploited unless the ratios of the median signal amplitude to least usable amplitude are equal for the two channels. Although a similar situation could occur in spaced-antenna diversity systems, such systems usually employ antennas of the same directivity characteristics and full advantage is taken of the favorable statistical relationship of the fading at the several antennas. This fact probably accounts for the preference shown to spaced-antenna diversity in practice and the limited use of polarization diversity.[3] The experiments reported here indicate that good diversity performance is attainable from the statistical behavior of the perpendicular polarization components of the received signals, but that the problem lies in developing antennas which fully utilize this behavior. These findings should serve to encourage further examination of the problem of polarization diversity antenna design.

Acknowledgments

The authors wish to acknowledge the contributions of Mr. Leroy W. LaChance, under whose supervision the data were collected. The work reported here was part of a research program sponsored by the Signal Corps Engineering Laboratories of Red Bank, N. J. The special test signals were provided by the Signal Corps Engineering Laboratories.

[3] With the simple antennas employed in the experiments reported here the median signal amplitude received by the vertical antenna was, on the average, about 3 db less than that received by the horizontal antenna. This is in good agreement with what would be expected from the directivity of the antennas and typical angles of arrival of the signals. Although objective measurements of the level of background interference were not obtainable, it appeared that the level of interference was about the same for the two antennas.

A Theory of Target Glint or Angular Scintillation in Radar Tracking*

RICHARD H. DELANO†, ASSOCIATE, IRE

Summary—**A theory is presented to describe the statistical aspects of tracking a complex isolated structure, such as an aircraft or naval vessel, by radar. The results are expressible in simplest form when the target subtends an angle small compared with the beamwidth. Other situations require special consideration and treatment, but can be attacked by the same general methods. However, when the angle subtended by the target is small, a single description applies to all radar tracking systems. An apparent and an effective radar center are defined and their statistical properties derived. Special treatment is given to additional noise arising in conical scanning due to amplitude fluctuations as such. The theory provides information relating to the spectra as well as to the probability densities and rms values of the pertinent quantities. It must be understood that the theory is approximate, is based on a particular model of the target, and leaves the determination of certain critical parameters to experiment in the case of any particular target.**

Introduction

THE PROBLEM of amplitude fluctuations in chaff return, sea return, ground return, ship return and aircraft return has been the subject of much investigation, effort and speculation. In many situations the probability density function of the echo amplitudes follows the Rayleigh distribution. In other cases the echo amplitudes follow the probability law of the envelope of a sine wave plus narrow band thermal noise. A summary of much representative work in this field is given in chapter 6, volume 13, of the M.I.T. Radiation Laboratory Series,[1] where many additional references can be found. In all such work the Rayleigh distribution of amplitudes is explained by the model of an infinite number of random scatterers with statistically independent amplitudes and phases, in fact, independent phases are enough, the amplitudes can even be constant. The infinity of the number of scatterers is not critical, even 5 or 6 is close to infinity for the purposes of this problem, provided the amplitudes of the scatterers are roughly equal. (See page 554, Reference 1.)

The assumption of many independent scatterers, or more specifically, of many equivalent point source radiators, to represent the radar target is the basis for the method presented in this paper. Furthermore it is convenient to consider first the case where all of the equivalent point sources are close to the tracking axis, i.e. where the tracking antenna is not in the process of "resolving" one source from another.

It is assumed in the above model of the target that phase differences are the most important cause of signal fluctuations when observing the target over a small

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† Hughes Research and Development Laboratories, Culver City, Calif.

[1] D. E. Kerr, "Propagation of Short Radio Waves," McGraw-Hill Book Co., New York, N. Y.; 1951. (The present work was completed before publication of this book.)

range of aspect angles. The derivations given here are concerned primarily with stationary statistics. Actually, as the target changes aspect by gross amounts, the nature of the target changes also; specifically, the rms amplitudes and the positions of the equivalent point sources change, and as a result, the mean radar center, later defined, changes. This change is assumed to be slow and continuous, so that in any small angular region the statistics of the target may be regarded as stationary. Multiple reflections are ignored. Polarization is not considered specifically, but is implicitly taken into account in that each polarization contributes separately but differently to the final amplitude and phase of each signal *at the output of the antenna.*

Derivation of the Basic Tracking Equation

The amplitude or envelope properties are well known. From N signals of amplitude $a_n(t)$ and rf phase, $\theta_n(t)$ *measured at the antenna output terminals*, the total vector rf signal is

$$V_T = \sum_{n=1}^{N} a_n e^{j\theta_n} = \sum_{n=1}^{N} a_n \cos\theta_n + j\sum_{n=1}^{N} a_n \sin\theta_n$$

$$= \alpha_1 + j\alpha_2 = Ee^{j\theta_r}. \tag{1}$$

As N approaches infinity (assuming all the $\overline{a_n^2}$ roughly equal) $\alpha_1(t)$ and $\alpha_2(t)$ come to have normal or Gaussian distributions and the envelope $E(t)$ has then a Rayleigh probability density. If $E(t)$ is Rayleigh distributed, the standard deviation of E is $\sqrt{(4/\pi)-1}\,\overline{E}=0.52\overline{E}$ which is the total fluctuation of E about its mean $\overline{E}$, no matter what the spread of this fluctuation in frequency.

In angular tracking, each rf signal $a_n e^{j\theta_n}$ must have an additional part due to the instantaneous tracking error between the antenna tracking axis and the angular position of the equivalent point source radiator. With conical scanning this additional part is an almost sinusoidal amplitude modulation, the amplitude and phase of which modulation are the polar co-ordinates of the angular error. Thus, for small angular errors the nth signal is

$$a_n[1 + b_0(\epsilon_n)\cos(\omega_s t - \phi_n')]e^{j\theta_n}$$

$$\simeq a_n[1 + b_0\epsilon_n \cos(\omega_s t - \phi_n')]e^{j\theta_n} \tag{2}$$

$$a_n = a_n(t),\ \epsilon_n = \epsilon_n(t),\ \theta_n = \theta_n(t) \text{ and } \phi_n' = \phi_n'(t)$$

where the constant b_0 is the fractional modulation per unit of angular error ϵ and ϕ_n' is the direction of the angular error. The essential point here is the assumption of linearity of modulation coefficient with angular error. The total rf signal is the sum of all the signals of the type given in (2).

The signal for conical scanning can be considered as broken up into three parts, corresponding to a sum signal and two difference signals. The sum of terms of the form given in (2) can be expressed as

$$V_{TM} = \sum_{n=1}^{N} a_n[1 + b_0\epsilon_n \cos(\omega_s t - \phi_n')]e^{j\theta_n}$$

$$= V_T + \cos\omega_s t \sum_{n=1}^{N} a_n b_0 \epsilon_{1n} e^{j\theta_n}$$

$$+ \sin\omega_s t \sum_{n=1}^{N} a_n b_0 \epsilon_{2n} e^{j\theta_n} \tag{3}$$

where

$$\epsilon_{1n} \cong \epsilon_n \cos\phi_n' \tag{4a}$$

$$\epsilon_{2n} \cong \epsilon_n \sin\phi_n'. \tag{4b}$$

The modulations $\sin\omega_s t$ and $\cos\omega_s t$ provide error-signals which can be separated out and referred to two perpendicular tracking planes, which can be called plane 1 and plane 2 in agreement with the above notation.

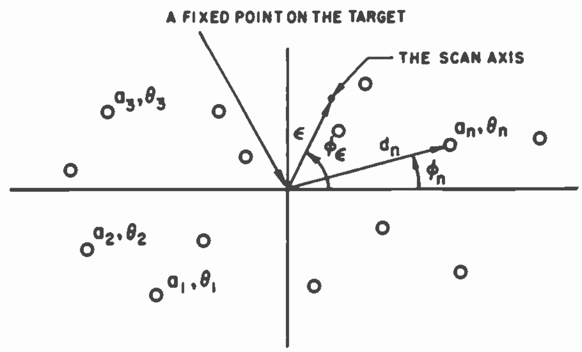

Fig. 1—Mathematical representation of the target in a plane perpendicular to the line of sight.

It is convenient to express ϵ_{1n} and ϵ_{2n} as the sum of two parts, the first, the deviation of the antenna tracking axis from some fixed point on the target, which is independent of n, and second the deviation of the position of the nth equivalent point source radiator from this fixed point. Thus we define

$$\epsilon_{1n} = -\epsilon_1 + \delta_{1n} \tag{5a}$$

$$\epsilon_{2n} = -\epsilon_2 + \delta_{2n} \tag{5b}$$

where

$$\tan\delta_{1n} = \frac{d_n\cos\phi_n}{R} \simeq \delta_{1n} \tag{6a}$$

$$\tan\delta_{2n} = \frac{d_n\sin\phi_n}{R} \simeq \delta_{2n} \tag{6b}$$

and d_n is the linear distance at range R of the nth equivalent point source radiator from the line through the radar and the fixed point on the target and ϕ_n is the direction of d_n relative to some reference direction, say, horizontal. Fig. 1 illustrates these quantities in a plane perpendicular to the line of sight (LOS). With this substitution (3) becomes

$$V_{TM} = V_T[1 - b_0\epsilon_1 \cos \omega_s t - b_0\epsilon_2 \sin \omega_s t] + \cos \omega_s t \sum_{n=1}^{N} a_n b_0 \delta_{1n} e^{j\theta_n} + \sin \omega_s t \sum_{n=1}^{N} a_n b_0 \delta_{2n} e^{j\theta_n}. \tag{7}$$

Further discussion will be simplified if the terms with subscript 2 are dropped and only one tracking channel is considered at a time. Under the assumption of small ϵ_{1n} and ϵ_{2n} the interactions between the two channels are negligible. Thus all pertinent information is obtained by considering

$$V_{TM1} = V_T[1 - b_0\epsilon_1 \cos \omega_s t] + \cos \omega_s t \sum_{n=1}^{N} a_n b_0 \delta_{1n} e^{j\theta_n} \tag{8}$$

since the subscript 1 is now superfluous, we shall drop it, and the equation can apply to either channel.

Let us now expand the identities of (1) to include the additional modulation terms

$$V_T = \sum_{n=1}^{N} a_n e^{j\theta_n} = E e^{j\theta_r} = \alpha_1 + j\alpha_2 \tag{9a}$$

$$\sum_{n=1}^{N} a_n b_0 \delta_n e^{j\theta_n} = E_s e^{j\theta_s} = \beta_1 + j\beta_2. \tag{9b}$$

As N approaches infinity α_1 and α_2 become normally or Gaussianly distributed, and so do β_1 and β_2. The asymptotic independence of β_1 and β_2 is easily demonstrated. A particular choice of origin for the δ_n (the fixed point on the target) achieves the independence of the α's and β's, since with normally distributed variables only the mean product has to equal zero to give complete independence

$$\overline{\alpha_1\beta_1} = b_0 \sum_n \sum_m \overline{a_n a_m \delta_m \cos \theta_n \cos \theta_m} = b_0 \sum_n \overline{a_n^2}\delta_n \overline{\cos^2 \theta_n} = \frac{1}{2} b_0 \sum_{n=1}^{N} \overline{a_n^2}\delta_n = 0 \tag{10}$$

if the origin is chosen so as to make this mean cross-product zero the asymptotic independence of α_1 and β_1 is established. The condition that $\overline{\alpha_2\beta_2}$ be zero also results in (10). The statistical independence of the a_n and θ_n was assumed in (10). If the amplitudes a_n are constant with time, the bar over a_n^2 can be removed in (10). With the origin properly chosen all the quantities in (9a) and (9b) are asymptotically independent.

With an actual radar target it is well to bear in mind that the point defined by (10) is a slowly varying function of aspect. If this point is a rapidly varying function of aspect, the theory presented here does not apply.

Linear detection of $V_{TM} = E_T e^{j\theta_T}$ gives the envelope E_T, whereas square-law detection gives the square of the envelope E_T^2. E_T^2 is easily obtained as the dot product or inner product of V_{TM} with itself. This dot product is (assuming ϵ is small also)

$$\begin{aligned} E_T^2 = V_{TM}\cdot V_{TM} &= [\alpha_1(1 - b_0\epsilon \cos \omega_s t) + \beta_1 \cos \omega_s t]^2 + [\alpha_2(1 - b_0\epsilon \cos \omega_s t) + \beta_2 \cos \omega_s t]^2 \\ &= (\alpha_1^2 + \alpha_2^2)(1 - 2b_0\epsilon \cos \omega_s t) + 2(\alpha_1\beta_1 + \alpha_2\beta_2) \cos \omega_s t + \text{terms} \\ &\simeq E^2(1 - 2b_0\epsilon \cos \omega_s t) + 2(\alpha_1\beta_1 + \alpha_2\beta_2) \cos \omega_s t \end{aligned} \tag{11}$$

and

$$\begin{aligned} E_T &\simeq E(1 - b_0\epsilon \cos \omega_s t) + \frac{\alpha_1\beta_1 + \alpha_2\beta_2}{E} \cos \omega_s t \\ &= E(1 - b_0\epsilon \cos \omega_s t) + [\beta_1 \cos \theta_r + \beta_2 \sin \theta_r] \cos \omega_s t \\ &= E - b_0\epsilon E \cos \omega_s t + U_a \cos \omega_s t \\ &= E + [U_a - U_b] \cos \omega_s t. \end{aligned} \tag{12}$$

Equation (12) states the significant result that the total signal component at ω_s (the tracking error-signal) is composed of two parts: (a) the useful signal tending to pull the tracking axis back to the geometrical center described by (10) which signal is $-b_0\epsilon E \cos \omega_s t$; and (b) an independent random error-signal $(\beta_1 \cos \theta_r + \beta_2 \sin \theta_r) \cos \omega_s t$ which can be called the angular scintillation error-signal. In addition, the envelope $E(t)$ very often contains components near the frequency ω_s which give error signals of considerable importance. These will be discussed later.

As the number of sources, N, approaches infinity, U_a approaches a Gaussian distribution for the same reason that E becomes Rayleigh distributed. For fixed θ_r the quantity $U_a = \beta_1 \cos \theta_r + \beta_2 \sin \theta_r$ is Gaussian with zero mean since it is the sum of two Gaussian variables with zero mean. Since the variance of U_a is independent of θ_r,

$$\overline{U_a^2} = \overline{\beta_1^2} \cos^2 \theta_r + \overline{\beta_2^2} \sin^2 \theta_r = \overline{\beta_1^2} = \overline{\beta_2^2} = \sum_{n=1}^{N} \frac{1}{2} b_0^2 \overline{a_n^2} \delta_n^2 \tag{13}$$

it follows that U_a is Gaussian independent of θ_r as long as β_1 and β_2 are independent of θ_r, which they are. The above expression has been expressed in terms of the properties of the point sources, namely, the mean square amplitudes $\overline{a_n^2}$ and the co-ordinates δ_n. The amplitudes $a_n(t)$ have been assumed statistically independent of the phases $\theta_n(t)$.

If, for example, the $\overline{a_n^2}$ are all equal, the mean square value of U_a is

$$\overline{U_a^2} = \frac{1}{2} b_0^2 \overline{a_n^2} \sum_{n=1}^{N} \delta_n^2 = \frac{1}{2} b_0^2 \overline{N a_n^2 \delta_n^2} = \frac{1}{2} b_0^2 \overline{E^2}\overline{\delta_n^2} = \frac{1}{2} b_0^2 \overline{E^2} \frac{\overline{d_n^2}}{R^2}. \tag{14}$$

The restoring signal is $U_b = b_0\epsilon E$. However, on the average only $b_0\epsilon\overline{E}$ is useful; the remainder, $b_0\epsilon(E - \overline{E})$ has a mean of zero and is a noise whose rms value is proportional to ϵ. If ϵ is small (as assumed) this noise can be neglected, but if a very large steady state error ϵ is used experimentally, say, then this noise will dominate all other sources of error. If U_a is normalized with respect to the mean useful signal per unit angular error, we obtain,

$$\eta_{rms} = \frac{[U_a]_{rms}}{b_0 \overline{E}} = \delta_{rms} \sqrt{\frac{\overline{E^2}}{2\overline{E}^2}} = \sqrt{\frac{2}{\pi}}\,\delta_{rms}. \quad (15)$$

η_{rms} as defined by this equation will be called the rms *effective* radar center fluctuation about the mean radar center. This result is in terms of the rms angle δ_{rms}; the relation $R\delta_{rms} = d_{rms}$ expresses η_{rms} in terms of a fixed rms displacement or distance at the target, where R is range to the target.

From (11) we can obtain the corresponding ratio when square-law detection is used

$$\eta_{rms}' = \frac{[EE_s \cos(\theta_r - \theta_s)]_{rms}}{\overline{E^2}} = \frac{1}{\sqrt{2}}\,\delta_{rms}. \quad (16)$$

Square-law detection is observed to be slightly superior as regards its effect on the rms noise angle due to angular scintillation.

Illustrative of (15) is the case where all the radiators are concentrated into two equal groups separated by a length L at range R. This case maximizes η_{rms} for a given L, and the result is obviously

$$\eta_{rms} = \frac{L}{\sqrt{2\pi}\,R}. \quad (16a)$$

If the sources are uniformly spaced along the length L, we have

$$\eta_{rms} = \frac{L}{\sqrt{6\pi}\,R} \quad (16b)$$

or, if they are concentrated into four equal groups uniformly spaced along L

$$\eta_{rms} = \sqrt{\frac{5}{18\pi}}\,\frac{L}{R}. \quad (16c)$$

Although common sense and speculation can be used to estimate both L and the distribution of sources a priori, experimental measurement is still required in any specific case.

Although these results have been derived specifically for conical scanning, they are equally applicable to any system which develops any kind of modulation on the signal from each source which is linear with angular error and which is in phase with the unmodulated signal from that source (or effectively in phase when used by the system). Essentially all linear modulation systems fall in this category.

Properties of the Apparent Radar Center

The next important results to be derived from (12) which gives the total angular error-signal in one tracking channel are the properties of the "apparent radar center" whose definition is as follows. The apparent radar center is the position ϵ of the antenna axis for which the error-signal is instantaneously zero; let this value of ϵ be designated as ϵ_0. This definition ignores noise due to components of $E(t)$ near ω_s, which is treated later. Under the assumptions which make (12) valid, ϵ_0 is single valued, or, in other words, ϵ_0 is single valued for a target small compared to a beamwidth and for ϵ_0 small compared to a beamwidth. From this definition and from (12), assuming linear envelope detection, ϵ_0 is given by

$$\epsilon_0 = \frac{U_a}{b_0 E} = \frac{\beta_1 \cos\theta_r + \beta_2 \sin\theta_r}{b_0 E} = \frac{E_s \cos(\theta_r - \theta_s)}{b_0 E}. \quad (17)$$

Since we are at present confining our attention to a single tracking plane, U_a is Gaussianly distributed with zero mean and E is Rayleigh distributed. Since U_a and E are independent it is relatively easy to derive the probability density of their ratio ϵ_0. The probability distribution of ϵ_0 under these circumstances is a special case of the Student's t distribution in statistics with 2 degrees of freedom. The variable t in the Student's t distribution is the normalized ratio of sample mean to sample standard deviation when n independent samples of a Gaussianly distributed random variable are observed.[2] This interesting but somewhat unrelated fact provides us with the probability density of ϵ_0. However, the following results are also derived in the Appendix which considers the general problem of the probability density of the ratio of two independent random variables. In a single tracking channel this probability density is

$$P(\epsilon_0) = \frac{b_0 E_{rms}}{\sqrt{8}\,U_{a\,rms}}\left(1 + \frac{1}{2}\,\frac{b_0^2\overline{E^2}}{\overline{U_a^2}}\,\epsilon_0^2\right)^{-3/2}. \quad (18)$$

For the second example previously cited, radiators a_n uniformly spaced along a length L (perpendicular to the line of sight from the radar), this probability density reduces to

$$P(\epsilon_0) = \sqrt{3}\,\frac{R}{L}\left(1 + \frac{12R^2}{L^2}\,\epsilon_0^2\right)^{-3/2}. \quad (19)$$

One interesting property of this distribution is the fraction of the time ϵ_0 points off the radar target in the tracking plane, i.e. lies outside the angular region of L/R radians, which in this case turns out to be

$$2\int_{(1/2)(L/R)}^{\infty} P(\epsilon_0)\,d\epsilon_0 = \int_{\sqrt{3}}^{\infty}(1 + x^2)^{-3/2}\,dx$$
$$= 1 - \sqrt{\frac{3}{4}} = 0.134 \quad (20)$$

or 13.4 per cent of the time. Another property of some interest is the second moment, or mean square of ϵ_0.

[2] P. G. Hoel, "Introduction to Mathematical Statistics," John Wiley and Sons, Inc., New York, N. Y.; 1947.

Since ϵ_0 is *not* Gaussianly distributed, as is U_a, for example, the theoretical distribution of ϵ_0 gives infinite mean square or mean fourth power, and so forth, for ϵ_0, i.e.

$$\int_{-\infty}^{\infty} \epsilon_0^2 P(\epsilon_0) d\epsilon_0 = \frac{1}{2} \int_{-\infty}^{\infty} \frac{x^2 dx}{(1+x^2)^{3/2}} = \infty. \quad (21)$$

This result violates the initial assumption that ϵ_0 is always small compared to a beamwidth. However, it points out the fact that dividing U_a by E causes the large values of ϵ_0 to be much more probable than if ϵ_0 were Gaussianly distributed.

To the extent that a very rapid AGC divides the total signal of (12) by $E(t)$, these remarks apply also to such an AGC. If the scan modulation components are very small, and if the bandwidth of $E(t)$ is low enough a rapid AGC acts in approximately this manner.

In considering both tracking channels simultaneously a complete description of the two dimensional statistics of U_a and ϵ_0 will not be presented here. However, it is useful to consider under what circumstances the U_a's are statistically independent in the two perpendicular tracking channels. Examination of (7) shows the two complex vectors which need to be independent. These are $\sum_{n=1}^{N} a_n \delta_{1n} e^{j\theta_n} = \beta_1 + j\beta_2$ and $\sum_{n=1}^{N} a_n \delta_{2n} e^{j\theta_n} = \gamma_1 + j\gamma_2$. For simplicity let us assume that all the δ's are small so that (6a) and (6b) apply. Then it is easy to show that independence of *all* the components of the above two complex vectors is assured if a single summation vanishes, namely

$$\overline{\beta_1\gamma_1} = \overline{\beta_2\gamma_2} = \frac{1}{2} \sum_{n=1}^{N} \overline{a_n^2} \frac{d_n^2 \cos\phi_n \sin\phi_n}{R} = 0. \quad (22)$$

If (22) holds, the error-signals in the two channels are statistically independent, and are Gaussian in the case of U_a. Equation (22) holds whenever there exists any one axis through the target plane (or a great circle through the target) with respect to which the equivalent point source radiators are symmetrically located both in angular, or linear, distance and in amplitude a_n, assuming always that one of the tracking channel directions coincides with this axis. Equation (22) also implies that if the pattern of point sources is identically symmetrical around any two perpendicular axes, the error-signals U_{a1} and U_{a2} are independent with equal standard deviations no matter what the orientation of tracking axes.

As an example of this latter double symmetry consider equal point sources uniformly spaced over a circular area of radius ρ. This double symmetry allows easy extension of the results for tracking in a single plane to three dimensional tracking. In the case of the apparent radar center, the probability density is

$$P(\epsilon_0') = \frac{8R^2}{\rho^2} \frac{\epsilon_0'}{\left[1 + \frac{4R^2}{\rho^2}\epsilon_0'^2\right]^2}. \quad (23)$$

This distribution also predicts an infinite value for $\overline{\epsilon_0'^2}$, as it must. The total probability that ϵ_0' exceeds ρ/R, i.e. lies outside of the circular target is

$$\int_{\rho/R}^{\infty} P(\epsilon_0') d\epsilon_0' = 2\int_{2}^{\infty} \frac{x dx}{(1+x^2)^2} = \frac{1}{5}. \quad (24)$$

The Statistical Nature of the Tracking Transfer Function

Returning to consideration of tracking in a single plane, we can see from (12) that the restoring error-signal is proportional to $E(t)$ as well as to ϵ. It must inevitably follow, unless the AGC is fast, that the antenna tracking equations relating antenna tracking axis to the radar center of the target are not constant coefficient linear differential equations whose properties are easily treated by the use of complex transfer functions $Y(\omega)$ or $Y(p)$. The differential equations involved will have coefficients which contain $E(t)$, a statistical variable, in addition to the forcing function U_a, also statistical. The mathematical treatment of such equations is not at present in a state of razor sharp precision.

Physical reasoning reveals some common situations where the variability of the useful signal due to $E(t)$ will have practically no effect. If the spectrum of E is sufficiently broad, i.e. if E fluctuates up and down fast enough relative to the time constant or averaging time of the tracking servo, the total applied error-signal after such averaging will differ only slightly from the ensemble average $-b_0\epsilon\overline{E}$. In such cases as far as the tracking equation is concerned $-b_0\epsilon E$ can be replaced by $-b_0\epsilon\overline{E}$ and constant coefficient equations result. Certain solutions of tracking performance obtained on analogue computers at Hughes Aircraft Company have shown that a ratio of, say, 10 to 1 in scintillation to tracking bandwidth is quite adequate for the above substitution of $\overline{E}$ for E. When this substitution is made the angular error-signal is just as though the target were a point source fluctuating in angular position by an amount η_{rms} as given in (16).

Spectra of E and U_a

The spectrum of narrow band noise which has been detected with a linear or square-law detector is easily calculated for a square-law detector and somewhat less easily calculated for a linear detector.[3] Precisely the same situation applies to the random signals which produce E and U_a. Since it has been shown[3] that the shapes of the detected spectra are only very slightly different for square-law and linear detection, we shall consider here only the square-law case. Equation (11) shows the squared envelope to be

[3] J. L. Lawson and G. E. Uhlenbeck, "Threshold Signals," Sec. 3.8, vol. 24, M.I.T. Radiation Lab. Series.

$$E^2 = \alpha_1^2 + \alpha_2^2 \tag{25}$$

and the error-signal corresponding to U_a to be proportional to $\alpha_1\beta_1+\alpha_2\beta_2$. The question of the magnitudes of the spectra is not important here, because the spectra can be normalized later using the well known relation that the total integral of the power spectrum of any quantity over all frequency is equal to the variance or square of the standard deviation of that quantity, which is known for both E and U_a.

The shape of the spectrum of E^2 (hence of E) can be determined from the spectra of α_1 and α_2. Since α_1 and α_2 have identical spectra either will do. The power spectrum of α_1^2 is just the convolution of the power spectrum of α_1 on itself.[4] Although the spectrum of $E(t)$ can be measured, there are many simple situations in which it can be calculated as well. For example if a line of uniformly spaced randomly phased point sources rotates at a constant angular velocity with respect to the LOS, the spectrum of $\alpha_1(t)$ is rectangular and the spectrum of α_1^2 is triangular, maximum at zero frequency and dropping to zero spectral density at the highest beat frequency, namely that between the two outside point sources.

In like manner the spectrum of $\alpha_1\beta_1+\alpha_2\beta_2$ can be obtained by taking the convolution of the spectrum of α_1 on the spectrum of β_1. In cases where there is no dependence of the rate of change of phase θ_n on position δ_n or d_n/R, the spectra of β_1 and of α_1 are usually identical. In other cases the spectrum of β_1 is different but its calculation involves no real problem if the spectrum of α_1 can be determined. In no case will the bandwidth of the amplitude fluctuations $E(t)$ differ significantly from the bandwidth of U_a.

Additional Noise Due to Amplitude Fluctuations in $E(t)$

In addition to signal components at frequency ω_s of amplitude U_a and $-U_b$, the actual envelope $E(t)$ may have noise components close to ω_s. These components are interpreted by the receiver as real signals and, unlike U_a, have no definite relation to the size or geometry of the collection of point sources which we call the target. Any mechanism at all giving rise to fluctuations at this frequency or close to it produces an additional noise term. Problems of this sort are considered in section 6.10 of vol. 25, M.I.T Radiation Laboratory Series. However this source[5] states that the rms fluctuations in amplitude about the mean are found in practice to be about $\frac{1}{4}$ of the mean, whereas with the Rayleigh distribution the amount predicted is 0.52 times the mean.

If the spectral shape for $E(t)$ is known or can be determined, the actual magnitude of the spectral density can be determined through the identity (basic to the definition of power spectrum)

$$\overline{E^2} - \overline{E}^2 = \left(\frac{4}{\pi} - 1\right)\overline{E}^2 = \int_0^\infty \Phi(\omega)d\omega \tag{26}$$

where $\Phi(\omega)$ is the power spectrum of $E(t)$, or of $E(t)-\overline{E}$ and E is assumed Rayleigh distributed. The corresponding spectral density after phase detection, i.e. after the error-signals have been extracted from the signal E_T of (12), expressed as an equivalent angle, is

$$\Phi_F(\omega) = \frac{2\Phi(\omega_s)}{b_0^2\overline{E}^2} \quad \text{for} \quad \omega \simeq 0 \tag{27}$$

where the factor of 2 arises from the fact that both frequencies above and below ω_s contribute to the output noise at the difference frequency. This spectral density is the same in both tracking channels. The magnitude of this noise in angular units is independent of range to the target unless the spectrum of $E(t)$ is range dependent in some way.

Short Range Theory

When the target is large or the beamwidth is narrow or the range is sufficiently small, it may happen that one of the basic assumptions of the preceding theory is no longer satisfied. This assumption is that the angular error $\delta_n-\epsilon$ of each point source radiator is sufficiently small that its individual error-signal, or scan-modulation component, is small. When this condition is not satisfied by all the sources simultaneously for all ϵ's to be expected, the simplicity of the preceding theory is not possible. It is then no longer possible to divide the error-signal into two statistically independent parts, one of them proportional to both ϵ and the signal envelope. In fact it is no longer possible to consider the two tracking channels separately, as they interact. The error-signals in the two channels, and their vector sum, are functions of the orientation of the two tracking axes with respect to the target. The apparent radar center is no longer uniquely defined, and the rms error-signal depends on ϵ which, however, was also true for long range tracking but in a different manner. It is possible to derive equations for the mean and rms error-signals for fixed ϵ, but they will not be presented here. Calculations from these equations show how the mean error-signal slope decreases rapidly as the target comes to subtend two or three beamwidths.

Finite Number of Sources

The theory presented here has given results for a target whose equivalent point sources are infinite in number. From results in the literature on E, the absolute magnitude of N randomly phased sinusoidal components[6,1] it seems well established that five or six roughly

[4] S. O. Rice, "Mathematical analysis of random noise," *Bell Sys. Tech. Jour.*, vol. 25, p. 46; 1945.

[5] H. M. James, N. B. Nichols, and R. S. Phillips, "Theory of Servomechanisms," McGraw-Hill Book Co., New York, N. Y.; 1947.

[6] W. R. Bennett, "Distribution of the sum of randomly phased components," *Quart. of App. Math.*, vol. 5, pp. 385–393; January, 1948.

equal sources is remarkably close to infinity as far as the resulting probability density of E is concerned. An unpublished paper by A. Vazsonyi of Hughes Aircraft Company has shown that the rms value of η, as defined by (15), never exceeds the value given in (15) when the point sources are finite in number and of equal intensity. Even when N is as small as four, the above paper shows the η_{rms} is somewhat greater than 0.9 times the value given by (15). Thus the infinite source theory is slightly pessimistic in all cases but gives answers very close to the more rigorous answer from a finite number of reflectors even so.

Consider briefly a two source target. For two fixed amplitude signals it is easy to determine one particular property of the apparent radar center ϵ_0, and that is the phase and amplitude ratio required to put ϵ_0 outside the two sources. Imagine the scan axis pointed at the larger source, so that its scan modulation is zero. If the resultant of the two complex signal vectors is at an angle of more than 90° with respect to the small vector, its scan modulation will produce a modulation on the resultant out of phase with itself. Such a modulation tells the antenna to move away from the smaller source, i.e. outside the target. From simple geometrical considerations it is apparent in Fig. 2 that a smaller signal, added to the larger, whose phase and amplitude are such as to put the resultant completely in the circle fulfills the required qualifications.

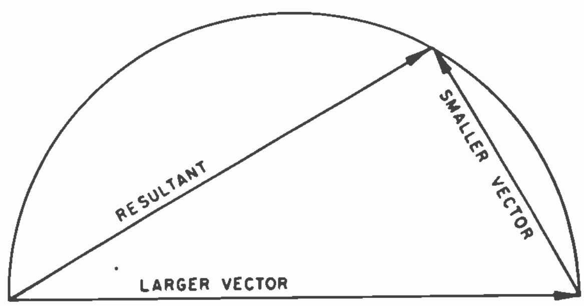

Fig. 2—Vector diagram illustrating when the smaller vector is more than 90° from the resultant.

When calculations are carried out on the two-radiator case, it is found that for essentially all plausible situations the rms fluctuations in effective radar center, suitably defined in this case, are smaller than those obtained for an infinite number of reflectors. In case the two amplitudes are independent statistical variables, Rayleigh distributed, the results immediately become identical to the infinite radiator case with each source taking the place of a large number of sources. This result seems reasonable at once since each source can be represented by an infinite number of sources all at the same location, the infinite number of sources producing the Rayleigh distribution of amplitudes.

APPENDIX

Probability Densities of a Ratio of Random Variables

Consideration of the apparent radar center ϵ_0, which makes the total error-signal instantaneously zero, requires that the probability density of the ratio of two random variables be determined. If we define random variables x, y and u related according to $u=x/y$ with probability densities $P_1(x)$, $P_2(y)$ and $P_3(u)$, with x and y independent, the probability densities must be related according to the following equation. Assume here for simplicity that x and y assume only positive values, as this assumption is no limitation on the generality of the results but implies that other cases must be treated separately and combined after $P_3(u)$ is determined for each portion of the problem.

$$\int_0^u P_3(u)du = \int_0^\infty P_2(y)dy \int_0^{uy} P_1(x)dx. \tag{28}$$

The integral $\int_0^{uy} P_1(x)dx$ is clearly the total probability that x is small enough so that, for fixed y, $(x/y) \leqq u$, and the total equation gives this probability averaged over all values of y. By differentiation of both sides of this equation we obtain

$$\begin{aligned} P_3(u) &= \int_0^\infty P_2(y)dy \frac{d}{du}\int_0^{uy} P_1(x)dx \\ &= \int_0^\infty yP_1(uy)P_2(y)dy. \end{aligned} \tag{29}$$

A useful example is when x is Gaussian and y is Rayleigh distributed, i.e.

$$P_1(x) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-x^2/2\sigma^2} \tag{30a}$$

$$P_2(y) = \frac{2y}{\mu^2} e^{-y^2/\mu^2} \quad y \geqq 0 \tag{30b}$$

then

$$\begin{aligned} P_3(u) &= \int_0^\infty \frac{y}{\sqrt{2\pi}\,\sigma} e^{-u^2y^2/2\sigma^2} \frac{2y}{\mu^2} e^{-y^2/\mu^2}dy \\ &= \frac{\mu}{\sqrt{8}\,\sigma}\left[1 + u^2 \frac{\mu^2}{2\sigma^2}\right]^{-3/2}. \end{aligned} \tag{31}$$

Due to symmetry considerations this expression applies to negative u. If both x and y have Rayleigh distributions with mean square values μ_1^2, and μ_2^2, respectively, $P_3(u)$ is

$$\begin{aligned} P_3(u) &= \int_0^\infty \frac{4y^3u}{\mu_1^2\mu_2^2} e^{-u^2y^2/\mu_1^2}e^{-y^2/\mu_2^2}dy \\ &= \frac{u\mu_2^2}{\mu_1^2}\left[1 + u^2 \frac{\mu_2^2}{\mu_1^2}\right]^{-2} \\ &= \frac{u\mu_2^2}{\mu_1^2}\left[1 + u^2 \frac{\mu_2^2}{\mu_1^2}\right]^{-2}. \end{aligned} \tag{32}$$

Addendum to:

"Pulses per Beamwidth for Radar"*

L. V. BLAKE

As the result of a conversation with Dr. W. M. Hall,[1] I would like to make the following addition to the above paper, which was published recently in PROCEEDINGS.

The result obtained in this paper was based on the square-law relation between pre-detection (IF) and post-detection (video) signal-to-noise ratios, for small signals. This was pointed out explicitly on page 771. As I probably also should have pointed out, this in effect restricts application of the results to the case of a radar which has an appreciable number of pulses per beamwidth, since for radars having few pulses, the minimum-detectable signal-to-noise ratio is likely to be appreciably greater than unity. The above-mentioned square-law relation then no longer applies. For large signal-to-noise ratios, in fact, the relation is approximately first-power (linear). For intermediate-level signals, the law would be intermediate between first-power and square-law.[2]

The square-law assumption was made because, as was pointed out, in most discussions of minimum detectable signals, one is concerned with weak signals. It has in fact been customary to make this square-law assumption in most discussions of the dependence of radar system sensitivity on the system parameters (e.g., pulse rate). Yet there has been an increasing tendency to design radars with fewer pulses per target per scan, and for these the small-signal analysis would not apply.

It was pointed out by Dr. Hall that the analysis of my paper can be readily applied to the case of a linear relationship between pre-detection and post-detection signal-to-noise ratios. This merely requires omission of equation (3), so that the law of variation of video signals with antenna-beam position is given by (2). This leads to the finding that the optimum integration angle is 1.2 times the half-power beamwidth (instead of 0.84), and the equivalent rectangular beamwidth is 0.67 times the half-power beamwidth (instead of 0.47). Then, however, the effective radar-sensitivity factor is 0.67 directly (whereas in the other case it was the square root of 0.47). Thus the new value of radar-system sensitivity reduction is 1.7 db, compared to the previous 1.6 db. This is an insignificant difference practically, and also mathematically, in view of the graphical method of solution of (10), and other approximations made.

This interesting result implies that approximately this loss figure can be applied for any intermediate case—that is, for any pre-detection and post-detection signal-to-noise-ratio relationship. The optimum integration angles and equivalent rectangular beamwidths for the intermediate cases would be intermediate between the values found in my paper and here. They could be calculated for any specified intermediate law. Generally speaking, however, it will usually happen that the minimum detectable signal will either be small, so that a one-half-power integration law can be assumed, or rather large, so that a first-power law will hold. In the intermediate cases it is likely to be difficult to make a close estimate of what law does apply.

As a guess, based on numerous experimental and theoretical results, the first-power law probably holds in the region of 5 pulses per target per scan or less, and the one-half-power law probably holds for 50 pulses or more (counted in the conventional manner based on half-power beamwidths). The latter figure would be obtained, for example, with an antenna of 6-degree beamwidth scanning at 6 rpm (36 degrees per second), with a 300-per-second pulse rate. It should be clearly understood that these numbers of pulses are guesses, given only to indicate order of magnitude.

* PROC. I.R.E., pp. 170–174; June, 1953.

[1] Raytheon Manufacturing Co., Newton, Mass.

[2] This is the effect of "suppression" of weak signals by noise, not to be confused with an actual nonlinearity of the detecting device, such as may occur with small input voltages. The effect considered here is much more fundamental and occurs when signals are small relative to the noise, regardless of the actual values of voltage involved. See W. R. Bennett, "Response of linear rectifier to signal and noise," *Bell Sys. Tech. Jour.*, vol. 23, pp. 97–113; January, 1944.

Correspondence

Calculation of the Gain of Small Horns*

Schelkunoff[1] has given curves for calculating the gain of electromagnetic horns having dimensions commonly used in practice. For horns having dimensions which are small in terms of wavelengths, and which therefore lie outside the range of the curves, it becomes necessary to revert to the original gain formula from which the curves were calculated. The formula involves the calculation of a number of Fresnel integrals, and is rather tedious to apply. By use of the following simple procedure the range of the curves may be effectively extended to cover any horn likely to be encountered in practice.

The method may also be employed to improve the accuracy of the curves, both in the case of small horns, and horns which already fall on the curves. This is achieved mainly by eliminating interpolation of the slant height, which is nonlinear and leads to the largest errors.

* Original manuscript received by the Institute, June 24, 1953; revised manuscript received July 30, 1953.

[1] S. A. Schelkunoff, "Electromagnetic Waves," D. Van Nostrand Co., N.Y., N.Y., pp. 363–365; 1943.

Correspondence

Let A, B, L_H and L_E be the H-plane and E-plane aperture dimensions and slant heights, respectively, in wavelengths, of the actual horn (which may either be too small to fall on the curves, or which may require interpolation between two values of slant height). A fictitious horn is now imagined having the dimensions (also in wavelengths):

$$a = k_H A \qquad l_H = k_H^2 L_H$$
$$b = k_E B \qquad l_E = k_E^2 L_E$$

where k_E and k_H are constants, to a high degree arbitrary, selected to make a, b, l_H and l_E fall somewhere in the range of the curves, and preferably in a region where they can by read with good accuracy. This accuracy, together with greater ease in reading the curves, may be attained most readily by making l_H and l_E coincide with one of the curves already plotted on the H and E plane graphs, respectively. This determines k_H^2 and k_E^2. The remaining interpolation of the abscissas can be carried out with no appreciable difficulty or inaccuracy. If the gain of this fictitious horn, as read from the curves in the usual manner, is g_{fict}, then the gain of the actual horn is given by:

$$g_{act} = \frac{g_{fict}}{k_E k_H}$$

or, in db

$$G_{act} = G_{fict} - 10 \log_{10} k_E k_H.$$

These formulas may easily be verified from the original expression for the gain given by Schelkunoff.

It is desirable to use values of k_E and k_H greater than unity, since this reduces the error incurred in the actual reading of the curves. This is automatically insured in the calculation of the gain of horns too small to fall on the curves, but in transferring larger horns from one part of the graph to another it is possible to choose the k's less than unity. This increases the error, and should be avoided whenever possible.

It should be remembered that the approximations involved in calculating Schelkunoff's gain formula get worse as the horn dimensions get smaller; however, results satisfactory for most practical purposes may still be achieved in the case of fairly small horns.

E. H. Braun
Naval Research Lab.
Washington 25, D. C.

Frequency Modulation and Instantaneous Frequency*

In a recent letter on this page[1] J. Shekel has in strong words rejected the idea of an instantaneous frequency of a frequency-modulated wave as being "fallacious" and "misleading." At the end of his letter, strangely enough, he accepts the concept itself but calls an "intuitive" *interpretation* of it erroneous. Mr. Shekel particularly criticizes the use of this concept in a paper by J. Marique.[2] Since the offending lines there are quoted from an earlier paper,[3] the author of this paper may be permitted to make a few comments, even though very few readers are likely to be disturbed by Mr. Shekel's arguments.

In harmonic analysis a frequency domain is defined strictly apart from the time domain. In the former, time does not exist, and everybody will agree that there, such concepts as instantaneous frequency and time-varying frequency are excluded. However, the concept of frequency is indispensable also in the time domain, where the instantaneous value of a time-varying frequency can be defined as rigorously as the instantaneous angular velocity of a spinning wheel or of a planet in its orbit about the sun.

Despite his enthusiasm for mathematical precision, Mr. Shekel neglects to specify the class of real time functions relevant to the discussion. All real time functions can of course be written in the form $f(t)=A(t) \cos \phi(t)$ with a very wide choice of $A(t)$ and $\phi(t)$, unless certain restrictions are applied to these functions. In the theory of modulated sine waves these restrictions in terms of $\omega_0+\theta(t)=\phi'(t)$ are that the frequencies of all essential spectral components of $A(t)$ and $\phi'(t)$ be small compared with the constant ω_0, that $\theta(t)\ll\omega_0$, and that $A(t)$ be bounded.

Mr. Shekel's assertions are:

1. The factoring of a time function $f(t)$ to the form $A(t) \cos \phi(t)$ is not unique; any definition of instantaneous frequency in terms of $\phi(t)$ is consequently ambiguous.
2. Even if $f(t)=A \cos \phi(t)$, where A is a constant, $d\phi/dt$ is not the instantaneous frequency.

The answer to the first point is that within the class of modulated waves as defined above the factoring is indeed unique. Nearly all the zeros of $f(t)$ are independent of $A(t)$ and determine uniquely the function $\cos \phi(t)$.

Also $\phi'(t)$ is then known with as high a mathematical precision as you wish, and it is hard to see any reasonable objection to calling it the instantaneous value of the radian frequency. When a new concept is introduced and defined, it can hardly be said to be right or wrong, but it can be criticized from the points of view of simplicity, usefulness, ambiguity, and consistency with established definitions and postulates. The definition of $\phi'(t)$ as the instantaneous radian frequency passes these tests quite satisfactorily.

It seems to be the lack of universality in the concept that concerns Mr. Shekel. He expects a quantity that can be calculated from observations on an arbitrary time function at any instant without knowledge of its previous history. Such a demand is not possible to meet, since the function must be observed over a long time before it can safely be classified as a modulated wave. Both $A(t)$ and $\phi'(t)$ may be transients, sequencies of transients, or random processes, which by their nature require observation over a long time before their characteristics can be considered known. However, despite their limited but well defined domain of applicability such concepts as frequency modulation, frequency deviation, and instantaneous frequency certainly justify their existence.

After a surprisingly long derivation Mr. Shekel correctly concludes that a sine function of constant frequency satisfies the differential equation $f''+\omega^2 f=0$. Apparently because f'' and f are easily observable at any instant, he prefers to use this equation as a definition of ω, but his extension of this definition to a variable $\omega(t)$ is of course just as improper as a direct substitution of a desired $\omega(t)$ for ω in $f(t)=A \cos (\omega t+\phi)$. After $f(t)$ has been found for all values of t in a sufficiently large interval T, $\phi(t)=\cos^{-1}(f(t)/A)$ can be plotted point by point, and $\phi'(t)$, the slope of the tangent to this curve, is an observable quantity with as high mathematical precision as $f(t)$ and $f''(t)$.

As illustrations Mr. Shekel quotes from the literature two statements and declares that their "apparent paradoxes" simply mean that they are "erroneous":

"The maximum of a response of a tuned RLC circuit to a voltage of a varying frequency does not occur when the instantaneous frequency (of this voltage) coincides with the resonance frequency of the circuit." This statement is quite correct, and since the phenomenon has a very simple physical explanation, there is actually nothing paradoxical about it.

"The spectrum of a frequency-modulated wave is wider than the range of variation of the instantaneous frequency." Any student who has grasped the idea that an *amplitude*-modulated wave will produce an appreciable response in a filter tuned to one of its side frequencies, even though the instantaneous frequency of the input, i.e., the carrier frequency, is outside the pass band of the filter, will readily accept this statement by analogy. The initial hurdle is the *intuitive* acceptance of the *formally* demonstrated equivalence of the time-domain and frequency-domain descriptions of a simple problem. The extension to more complicated problems later on requires no appreciable additional intuitive effort.

Gunnar Hok
Department of Elec. Eng.
University of Michigan
Ann Arbor, Michigan.

* Received by the Institute, May 21, 1953.

[1] J. Shekel, "'Instantaneous' frequency," Proc. I.R.E., vol. 41, p. 548; April 1953.

[2] J. Marique, "The response of RLC resonant circuits to EMF of sawtooth-varying frequency," Proc. I.R.E., vol. 40, p. 945; August 1952.

[3] G. Hok, "Response of linear resonant systems to excitation of a frequency varying linearly with time," *Jour. of Appl. Phys.*, vol. 19, p. 242; March 1948.

Contributors to Proceedings of the I.R.E.

James B. Angell (S'45-A'47) was born in Staten Island, N. Y., on December 25, 1924. He received the S.B. and S.M. degrees of the cooperative course in electrical engineering at the Massachusetts Institute of Technology in 1946, and an Sc.D. degree in electrical engineering from the same school in 1952.

JAMES B. ANGELL

Between 1946 and 1951 he worked as a research assistant in the Research Laboratory of Electronics at M.I.T., studying noise in tracking radars. Since 1951, he has been a project engineer in the Research Division of the Philco Corporation, where he has worked on microwave communication systems, various military projects, and, more recently, in leading a group studying transistor circuit applications.

Dr. Angell is a member of Tau Beta Pi, Eta Kappa Nu, and Sigma Xi, and an associate of the AIEE.

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George R. Arthur (S'47–A'51–M'51) was born in Philadelphia, Pa., on February 22, 1925. He received the B.E. degree with high honors from Yale University in 1948, and the M.E. degree in electrical engineering in 1949, during which time he held a Thomas Edison Fellowship. He received the Ph.D. degree from the Yale Graduate School in 1952.

GEORGE R. ARTHUR

From 1943 to 1946, he was an electronics technician in the U. S. Navy. While at Yale, he was a research assistant on a U. S. Signal Corps Project on pulse modulation. From 1949 to 1952, he was an instructor in electrical engineering at Yale. During this period, Dr. Arthur also served as a research engineer on projects on information theory and noise. Since 1952, he has been with the Sperry Gyroscope Company as a project leader on automatic flight control systems.

Dr. Arthur is a member of Sigma Xi, Tau Beta Pi, AIEE, ASEE, and the Yale Engineering Association.

❖

Bernard Berkowitz was born on June 7, 1918. He graduated from Lehigh University with honors in 1940, receiving the B.A. degree in physics.

For three years Mr. Berkowitz was employed by the Navy Department, principally in connection with the degaussing of mine sweepers. From 1943 to 1946 he worked on instrumentation for the Manhattan Project, first with the Kellex Corporation, and later with the Carbide and Carbon Chemicals Corporation.

B. BERKOWITZ

Mr. Berkowitz joined the Sperry Gyroscope Company in 1946, working on the development of an accelerometer. In 1947 he transferred to the antenna section, where recently he has been appointed a senior project engineer.

❖

William E. Bradley (SM'45–F'53) was born in Lansdowne, Pa., on January 7, 1913. He received the B.S. degree in electrical engineering from the University of Pennsylvania in 1936. In June of the same year, he joined the Philco organization, transferring early in 1937 from production to television research. He has been associated with research at Philco in the fields of television, microwave radar, frequency modulation, physical optics, and solid state physics. He became assistant director of the research division in 1945, director in 1946, and technical director in 1952.

W. E. BRADLEY

Mr. Bradley is a member of Sigma Xi, Tau Beta Pi, Eta Kappa Nu, American Physical Society, and Franklin Institute.

❖

Richard H. DeLano (A'48) was born in Los Angeles, Calif., on August 13, 1925. He received the B.S. and M.S. degrees from the California Institute of Technology in 1946. Since 1946 he has been employed in the Research and Development Laboratories of the Hughes Aircraft Company, where, at present, he is in the Theory and Analysis Department of the Guided Missile Laboratory. His work has been centered primarily in statistical and noise theory, in the application of these to radar tracking and servo problems, and to various problems in missile guidance and circuitry.

R. H. DELANO

Mr. DeLano is a member of Tau Beta Pi, and RESA.

❖

Palmer L. Edwards (A'48) was born on March 9, 1923, in Enterprise, Alabama. He received the B.S. degree in physics from Louisiana State University in 1944 and the M.S. degree in engineering sciences and applied physics, Harvard University, in 1947.

P. L. EDWARDS

Mr. Edwards has been employed at the Naval Ordnance Laboratory since July, 1944, except for two years spent in graduate studies at Harvard University. He is a research associate in the Explosives Research Department of the Naval Ordnance Laboratory. He is a member of Phi Kappa Phi.

❖

Lawrence P. Faber, Jr., was born in Palo Alto, Calif., on April 23, 1920. He served with the U. S. Army Air Force from 1941 to 1945. He received the B.S. degree in electrical engineering in 1948, and the M.S. degree in electrical engineering in 1951, from Washington University in St. Louis. He was associated with the Diversity Reception Research Project at Washington University from 1948 to 1952. Since 1952 Mr. Faber has been employed by Vickers Electric Division, Inc., of St. Louis.

L. P. FABER, JR.

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John L. Glaser (S'42–A'51–SM'52) was born in St. Louis, Mo., on January 21, 1921. He received the B.S. degree in electrical engineering in 1943, from Washington University in St. Louis. He served with the Anti-aircraft Artillery and Signal Corps during World War II. He was also an instructor at the M.I.T. Radar School, and a radar and communications officer in the Panama Canal Zone.

JOHN L. GLASER

In 1948 and 1952 respectively, he received the M.S. degree and the D.Sc. degree in electrical engineering from Washington University, while serving as Project Director of their Diversity Reception Research Project.

In 1952, Dr. Glaser joined the Bell Telephone Laboratories, New York, N. Y., where he now is engaged in systems engineering. He is a member of the JTAC Subcommittee on Study of Spurious Radio Emissions, and Sigma Xi.

❖

George L. Hall was born in Brandywine, Virginia, on February 18, 1926. He received the B.S. degree in physics from William and Mary College in 1949, and the M.S. degree in physics from Syracuse University in 1951, where he held a General Electric fellowship.

George L. Hall

During World War II, Mr. Hall served as a radar technician in the Army Air Corps and Signal Corps. From 1951 to 1953, he was employed in the electron-tube laboratory of Federal Telecommunication Laboratories, Inc., as a senior engineer on traveling-wave tubes and electron-beam devices.

At present, Mr. Hall is studying for his Ph.D. in physics at the University of Virginia, where he is associated with the electronics research laboratory. He is a member of Sigma Xi.

❖

Paul G. Hansel was born in Grand Island, Nebraska, on June 22, 1917. He attended the University of Kansas from 1935 to 1940, and for a short period in 1946, receiving a B.S. degree in Engineering Physics. From 1941 to 1947 he was engaged in the development of radio direction finders and special-purpose receivers at the Signal Corps Engineering Laboratories.

Paul G. Hansel

In 1947, he joined Servo Corporation of America. He is Chief Radio Engineer of that organization, and is concerned with the development of radio and radar instruments, navigation, systems, and apparatus for frequency control and measurement.

❖

James G. Holbrook (M'52) was born in Houston, Texas, on June 15, 1922. He entered the Air Force in 1941 to 1945, where his principal work was with long range navigational systems in the Pacific. Mr. Holbrook became affiliated with Stations KGMB and KHON in Honolulu, T.H., shortly after the war. In 1948 he joined the FCC in the Territory, but returned to the United States one year later for study. He received the B.S. degree from The Milwaukee School of Engineering in early 1952, and since has been with Northrop Aircraft, Los Angeles, where he is currently in charge of antenna research.

J. G. Holbrook

Mr. Holbrook is also a member of the American Physical Society.

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Dietrich A. Jenny (A'47) was born in Ennenda, Glarus, Switzerland, on August 15, 1920. He received his Diploma in Physics in 1946, and his Doctor of Natural Science degree in 1950, from the Department of Mathematics and Physics at the Swiss Federal Institute of Technology in Zürich Switzerland.

Dietrich A. Jenny

In 1947, Dr. Jenny joined the Laboratories Division of the Radio Corporation of America at the David Sarnoff Research Center in Princeton, N. J., where he worked on electron tubes, color television, and did the experimental part of his doctoral thesis on secondary electron emission. His more recent work was concerned with thermionic emission problems. Since 1951 he has been engaged in transistor and semiconductor research.

Dr. Jenny is a member of the American Physical Society and Sigma Xi.

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Robert E. Kansas (S'44–A'53) was born in New York City, N. Y., on March 4, 1926. He received the B.E.E. degree from the College of the City of New York in 1945, and the M.E.E. degree from the Polytechnic Institute of Brooklyn in 1947. During 1948 and 1949 he became a member of the Electrical Engineering Department of the College of the City of New York, teaching courses in electric-circuit theory, and dc and ac machinery.

Robert E. Kansas

From 1949 to 1952, as a graduate student at Harvard University, he completed requirements for the Ph.D. degree in applied physics. In 1952, he joined the Research Division of Philco Corporation, where he is engaged in research on the circuit implications of transistor physics.

Mr. Kansas is a member of Sigma Xi, Tau Beta Pi, Eta Kappa Nu, American Physical Society, and AAAS.

❖

Francis P. Keiper, Jr. (S'50–A'51) was born in Washington, D. C., on April 13, 1929. He received the B.E.E. degree from Cornell University with the first five-year engineering class in June, 1951. While at Cornell, he participated in the industrial co-operative plan.

Francis P. Keiper

Shortly after joining the Research Division of the Philco Corporation in 1951, Mr. Keiper became engaged in the evaluation of transistor devices and in the study of transistor circuits.

He is a member of Eta Kappa Nu.

❖

Daniel Levine (S'44–A'47–M'47) was born in New York, N. Y., on July 21, 1920. He received the B.S. degree from the University of Michigan in 1941, majoring in chemistry. The following year, during which he served as laboratory assistant in electrochemistry at the same University, he received the M.S. degree. In 1948, he received the M.S. degree from Ohio State University, with a major in electronics. In 1942 he entered the Army Air Corps, and attended radio and radar schools at Sioux Falls, S. D., Harvard, and M.I.T., following which he went into counter-measures work, and was engaged in Ferret activities in the Pacific Theater at the end of the war.

Daniel Levine

Upon his return to the United States in 1945, Mr. Levine was assigned to the radar laboratories at Wright Field, Ohio, and continued his project work at that laboratory following his separation from the armed forces. He is now Technical Consultant for the Search Radar Branch, Aircraft Radiation Laboratory, Wright Air Development Center.

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Kam Li (S'50) was born in 1927 in Canton, China. He received the B.S. degree from Chiao-tung University, Shanghai, in 1949, and the M.S. degree in electrical engineering from the Moore School of Electrical Engineering, University of Pennsylvania, in 1951.

Kam Li

In 1951, Mr. Li joined the electro-medical group of the Moore School of Electrical Engineering, and the Department of Physical Medicine, as a research assistant. He has been working on electrical properties of biological material at ultrahigh frequencies.

Philip Parzen (SM'52) was born on June 28, 1916, in Poland. He received the B.S. degree in physics from the College of the City of New York in 1939, and the M.S. degree in physics from New York University in 1946. He is completing work for the Ph.D. degree in mathematics at New York University.

PHILIP PARZEN

During the war he was employed at the Westinghouse Research Laboratories and, since 1947, at the Federal Telecommunication Laboratories, Inc., working on problems in microwave tubes and electromagnetic wave propagation.

In addition to his membership in IRE, Mr. Parzen is a member of the American Physical Society.

Herman P. Schwan (M'53) was born in 1915, in Germany. He studied physics, electrical engineering, and biophysics in Goettingen and Frankfurt, and spent two years in industry as an electrical engineer (Siemens Telefunken). He received the Ph.D. Degrees in physics and biophysics, in 1940 and 1946 respectively, from the University of Frankfurt, and was engaged in biophysical research and ultrahigh frequency development work from 1938 to 1947 at the Kaiser-Wilhelm-Institute at Frankfurt. From 1946 to 1947 he held positions as assistant director and assistant professor at the same institute.

H. P. SCHWAN

Dr. Schwan came to this country in 1947, and worked for the United States Navy's Aero-Medical Equipment Laboratory as a research specialist. Since 1950 he has been with the University of Pennsylvania and holds appointments as Associate Professor of Physical Medicine and Physics in Medicine in the Graduate School and School of Medicine, and as Assistant Professor of Electrical Engineering in the Moore School of Electrical Engineering. He heads the electromedical research team which has been organized at the University of Pennsylvania by the Electrical Engineering and Medical Schools, and is conducting research in the fields of biophysics and medical electronics.

He is a member of the American Association for the Advancement of Science, Franklin Institute, and an associate member of the AIEE.

Ruth F. Schwarz was born in Louisville, Ky., on July 12, 1925. She received the B.A. degree in physics from the University of Louisville in 1946, the M.A. degree in physics and the Ph.D. degree in physics from Radcliffe College in 1949 and 1953 respectively.

RUTH F. SCHWARZ

Mrs. Schwarz has been working with the Philco Corporation for the last year, where she is engaged in the transistor research and applications program of the corporation.

She is a member of the American Physical Society, and Sigma Xi.

Charles Süsskind (A'47–M'52) was born in 1921, in Prague, and received his secondary education in Czechoslovakia and in Great Britain. He graduated from the California Institute of Technology in 1948, and received the M.Eng. and Ph.D. degrees from Yale University in 1949 and 1951 respectively.

CHARLES SÜSSKIND

During the war, Dr. Süsskind served with the 8th Air Force in Europe as an airborne-radar specialist. His interest in the microwave field led to a doctoral thesis on artificial dielectrics. An article based on this dissertation, published by the British IRE, earned him the Clerk-Maxwell Premium for "the most outstanding paper published in the Institution's Journal" in 1952.

Since 1951, Dr. Süsskind has been a research associate at Stanford University, where he is engaged in microwave tube research and part-time teaching.

Dr. Süsskind is an associate member of the British IRE, and a member of the American Physical Society, The History of Science Society, and Sigma Xi.

John W. Tiley (A'43–M'45) was born in Philadelphia, Pa., on April 2, 1913.

Mr. Tiley was actively engaged in the radio service field long before completing high school in 1931. In 1940, he joined the Philco Corporation as a radio and television field service engineer. In 1943, he became a member of the Test Equipment Engineering Department, designing microwave test equipment for factory use. In 1946, he was transferred to the Research Division, where he was occupied in the designing of radar systems. Since 1949, he has been concerned with applied physics, particularly with semiconductors and transistors.

JOHN W. TILEY

Joseph F. Walsh was born in Albany N. Y., on April 29, 1927. Mr. Walsh received the B.S. degree in physics from Siena College in 1949, and the M.S. degree in physics from Rensselaer Polytechnic Institute in 1952.

JOSEPH F. WALSH

Since July 1952, Mr. Walsh has been associated with the transistor research program of the Philco Corporation. He is a member of American Physical Society, and Sigma Xi.

Dean A. Watkins (A'47–M'48–S'49–A'51) was born in Omaha, Neb., on October 23, 1922. He specialized in electrical engineering, receiving the B.S. degree from Iowa State College in 1944, the M.S. degree from California Institute of Technology in 1947, and the Ph.D. degree from Stanford University in 1951, where he was a Gerard Swope Fellow from 1950 to 1951.

DEAN A. WATKINS

In World War II, Dr. Watkins was an army engineer unit commander in the European and Pacific Theaters. He was employed by the Collins Radio Company from 1947 to 1948, and at the Los Alamos Scientific Laboratory from 1948 to 1949. From 1951 to 1953, he was employed by the Hughes Aircraft Company, where he was a member, and then head of the microwave tube section of the Research and Development Laboratories. Since 1949, Dr. Watkins has been engaged in microwave-tube research, specializing in traveling-wave tubes and backward-wave oscillators. In March, 1953, he returned to Stanford University, where he is now Associate Professor of Electrical Engineering, engaged in graduate teaching and research. He is a member of Sigma Xi, Tau Beta Pi, Eta Kappa Nu, Pi Mu Epsilon, and Phi Kappa Phi.

Richard A. Williams was born in Westmont, N. J., on July 20, 1924.

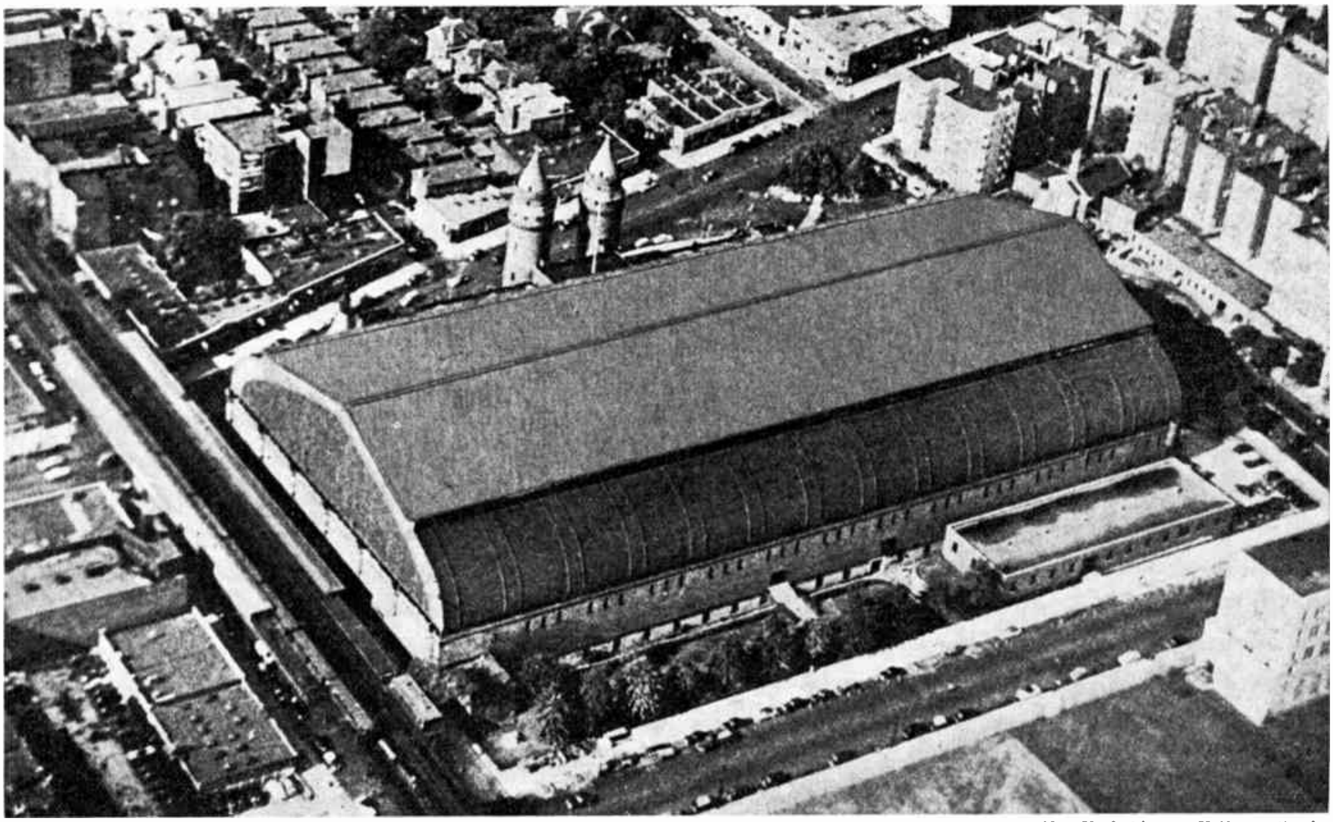
He was graduated from the University of Pennsylvania with the degree of B.A. in physics in 1947.

R. A. WILLIAMS

Since 1947, Mr. Williams has been a member of the Research Division of Philco Corporation, and has been engaged in the design and development of radar, airborne television, electronic tube and semiconductor device research. Mr. Williams is a member of the American Physical Society.

Institute News and Radio Notes

1954 IRE National Convention Exhibit Site



New York Airways Helicoper Service

Aerial view of New York City's Kingsbridge Armory, new site for IRE's Annual Convention, conveys some idea of vastness of exhibit area. Four acres of floor space, largest unobstructed area of the kind in the world under one roof, will accommodate over 600 exhibits all on one level.

IRE National Convention News

March 22 through 25 have been selected as the dates for the biggest and most important technical event of the coming year, the 1954 IRE National Convention. As in past years, the Convention will be held in New York City in two locations, the Waldorf-Astoria Hotel and a new exhibit site, the Kingsbridge Armory.

An outstanding Convention program is being planned to follow the same general format which has proved so successful in past years. Principal activities will include four days of informative technical sessions, a bigger and better Radio Engineering Show, the Annual Meeting of the Institute, a "get-together" Cocktail Party, and the Annual Banquet. All indications are that the attendance will exceed last year's record total of 35,000.

A particularly noteworthy feature of the Convention is the change in location of the exhibits from Grand Central Palace to the Kingsbridge Armory. The move, necessitated by the lease of Grand Central Palace to the United States Government, has proved to be a blessing in disguise. Among the many advantages of the Armory is that it boasts the largest unobstructed floor of any building in the United States. As a result, the entire Radio Engineering Show can now be housed on one floor, occupying over four acres.

This floor space will accommodate over 600 exhibitions, a 50 per cent increase over last year. To the member this means a corresponding increase in the information value of the Radio Engineering Show, for he will now have the unique opportunity of viewing the latest products of a substantial portion of the entire radio-electronic industry.

In addition to the increased size, the Kingsbridge Armory provides considerably improved facilities. Three well-equipped auditoriums will accommodate approximately half of the program of technical papers during all four days of the Convention. For the convenience of visitors, a large cafeteria is located within the building.

The Kingsbridge Armory is readily reached by bus and by two subway lines. Busses, free of charge to Convention registrants, will run at frequent and regular intervals between the Armory and the Waldorf-Astoria Hotel. Subway service between the two locations is excellent, requiring a walk of only one block.

A comprehensive program of over 200 technical papers is being organized by the Technical Program Committee with the help of all 21 IRE Professional Groups. Authoritative reports on the most important advances in every branch of the communications and electronics field will be heard during all four days of the Convention. Technical sessions and symposia will be held in three auditoriums at the Kingsbridge Armory and a like number at the Waldorf-Astoria Hotel. The complete program, including 100-word abstracts of all papers, will be published in the March issue of the Proceedings of the I.R.E.

Plans are under way to publish again the Convention Record of the I.R.E., to contain all available papers presented during the 1954 Convention.

The Annual Meeting of the Institute will be held on the morning of the opening day of the Convention. This meeting is planned especially for IRE members and will feature as principal speaker John D. Ryder, Head of the Electrical Engineering Department of the University of Illinois.

The popular "get-together" cocktail party will be held on Monday evening, March 22, in the Grand Ballroom of the Waldorf-Astoria Hotel. The Social activities will be climaxed by the Annual Banquet on Wednesday evening when a speaker of national prominence will deliver the principal address, and the Annual IRE Awards will be presented.

Further Convention details appear on page 1A of this issue.

Institute News and Radio Notes

"Electronics in Aviation"

"Electronics in Aviation" Day, a conference jointly sponsored by the Institute of Radio Engineers, Institute of the Aeronautical Sciences, Institute of Navigation, and the Radio Technical Commission for Aeronautics, will be held at the Hotel Astor on January 27, 1954 as part of the annual convention of the IAS.

At the morning session the following four papers will be presented: "Aircraft Control Systems," R. C. Seamans; "Operational Telemetering," M. Kiebert; "Long Range Navigation," J. A. Pierce; and "Magnetic Amplifiers-Automatic Pilots."

In the afternoon a symposium will be conducted on the general subject of training requirements and training devices, under the chairmanship of E. O. Carmody. Program will include a number of invited papers.

The evening session will deal with the proper use of air space, a serious problem in the effective use of modern aircraft.

It is expected that the general trend of the discussion and the subjects covered will be of considerable interest to many IRE members, not only those in the Professional Group on Aeronautical and Navigational Electronics, but also those in apparently unrelated fields.

Proceedings Index

This issue contains, in addition to the annual Proceedings Index, an index to the 1953 Convention Record. Due to space limitations, the "Transactions" Index will appear in a later issue of the Proceedings.

Calendar of

COMING EVENTS

IRE PGME Symposium on Electronic Plethysmography, University of Buffalo Medical School Auditorium, Buffalo, N. Y., December 10–11

IRE-IAS-ION-RTCA Conference on Electronics in Aviation, Astor Hotel, New York City, January 27

1954 Sixth Southwestern IRE Conference and Electronics Show, Tulsa, Okla., February 4–6

IRE-AIEE Conference on Transistor Circuits, Philadelphia, Pa., February 18–19

1954 IRE National Convention, Waldorf Astoria Hotel and Kingsbridge Armory, New York, N. Y., March 22–25

Society of Motion Picture & TV Engineers, 75th Annual Convention, Hotel Statler, Washington, D. C. May 3–7

IRE New England Radio Engineering Meeting (NEREM), Sheraton Plaza Hotel, Boston, Mass., May 7–8

IRE-AIEE-IAS-ISA National Telemetering Conference, Morrison Hotel, Chicago, Ill., May 24–26

1953 WESCON Luncheon

Among those at the Speakers' table at the All-Industry Luncheon, 1953 WESCON, are (l. to r.): Noel E. Porter, William Jamieson, Robert L. Sink, George W. Bailey, Joseph Landells, Donald G. Fink, Jesse E. Hobson, James Wilson McRae, and Norman H. Moore.

14,000 Attend 1953 WESCON

The 1953 Western Electronic Show and Convention, co-sponsored by the Seventh Region IRE and the West Coast Electronic Manufacturers Association, was held in the Civic Auditorium, San Francisco, Calif., August 19–21. Approximately 14,000 engineers, scientists, and technicians attended the technical sessions or visited the displays at the Conference, which was very successful from all standpoints.

During the three-day meeting there were 25 sessions at which technical papers were presented on the latest advances in the field of communications and radio-electronics.

Besides the technical sessions, four field trips were arranged which covered the U. S. Naval Electronic School; the Stanford Microwave Laboratory, the Sylvania Electric Co., and Varian Associates; the KPIX Television Studios; and the Chromatic Television Laboratories. There were also many exhibits on view, including one seen for the first time of Western historical electroniana, early electron tubes, loudspeakers, communication equipment, and newsclippings and photographs relating to electronic development.

Among the special events was the All-Industry Luncheon, at which Donald G. Fink, Director of Research of the Philco Corp., delivered an address on "The Transistor—Glamor Boy or Workhorse." The Luncheon program also included the presentation by Seventh Region IRE of the Second Annual Achievement Award to Simon Ramo (A'38–SM'44–F'-50) in recognition of "his leadership in the organization of industrial research and engineering and his devotion to the progress of the electronic art through the advanced training and education of the engineer."

Next year, the event is to be held in the Los Angeles area, where 1954 WESCON is scheduled for the Pan Pacific Auditorium, August 25–27.

Medical Electronics Symposium in Buffalo

The IRE Professional Group on Medical Electronics is co-operating with the Schools of Medicine and Engineering of the University of Buffalo in co-sponsoring a symposium on electronic plethysmography or blood volume measurement.

The symposium will be held co-incident with the formal dedication of the University of Buffalo's new medical school building on December 10–11, 1953. A two-day program is planned. Tours of research facilities in the Buffalo area will be interspersed with a series of papers by research personnel active in the field. The keynote address on Thursday, December 10, will be given at 10:00 A.M. by Dr. Jan Nyboer of the Dartmouth College Medical School. Dr. Nyboer has worked extensively in the field of impedance plethysmography.

Other papers will be given by such authorities as Dr. Sergei Feitelberg and Dr. Ray Megibow of Mt. Sinai Hospital, Dr. Henry Kalmus of the National Bureau of Standards, and Warren Tilton of Hathaway Instruments, Inc. A total of six to eight significant papers will be presented.

While the final program is incomplete at this date, the following papers are representative of those to be given: "Electronic Plethysmography," keynote address, Dr. Jan Nyboer, Dartmouth College Medical School; "An Electronic Flowmeter System," Dr. Henry Kalmus, National Bureau of Standards; "Design of Finger-Tip Plethysmographs with Photoelectric and Strain Gage Transducers," Dr. Ray Megibow, Mt. Sinai Hospital, New York City; and "Applications of the Electronic Plethysmograph in Blood Pressure Determination," J. Block, Cornell University Behavior Farm.

Institute News and Radio Notes

Five New Chapters Approved

At a recent meeting of the IRE Executive Committee, the establishment of the following Professional Group Chapters was approved: The Chicago Chapter of the Professional Group on Microwave Theory and Techniques, the Chicago Chapter of the Professional Group on Radio Telemetry and Remote Control, the Los Angeles Chapter of the Professional Group on Component Parts, the Philadelphia Chapter of the Professional Group on Engineering Management, and the Albuquerque-Los Alamos Chapter of the Professional Group on Microwave Theory and Techniques.

SMPTE Honors IRE Members

Among the thirteen leading scientists and engineers of the motion picture and television industries who were honored recently for outstanding technical achievements, were Otto H. Schade (M'40–SM'43–F'51) and Arthur V. Loughren (A'24–M'29–SM'43–F'44). The annual awards of the Society of Motion Picture and Television Engineers, highest recognition awarded for achievement in this field, were presented at the 74th semi-annual convention of the Society, which was held at the Hotel Statler in New York City on October 5–9.

Mr. Schade was cited for his outstanding technical paper, "Image Gradation, Graininess and Sharpness in Television and Motion Picture Images."

Mr. Loughren received the David Sarnoff Gold Medal Award "for his contribution to the development of compatible color television, including his active work on the principle of constant luminence adopted as part of the signal specifications of the National Television System Committee." Mr. Loughren was cited for his work as chairman of the color video standards panel of the NTSC and was described in the citation as "a guiding spirit and forceful exponent of compatible color television."

1953 Convention Record of the I.R.E.

A limited number of copies of the Convention Record of the I.R.E., containing approximately 190 papers presented at the 1953 IRE National Convention on March 23–26, are available at the Institute of Radio Engineers, 1 East 79 Street, New York 21, N. Y. Prices of individual Parts and the subject matter of each Part are given below. To insure delivery, place your order promptly.

Convention Record of the I.R.E.

Part	Title	Subject	IRE Members	Nonmembers	Public Libraries and Colleges
1	Radar and Telemetry Sessions: 6, 12, 37, 43	Navigation Airborne Equipment Radio Telemetry Remote Control	$1.00	$3.00 (Out of stock)	$2.40
2	Antennas and Communications Sessions: 1, 7, 13, 18, 28	Antennas Propagation Mobile Communications Communication Systems	1.25	3.75	3.00
3	Audio Sessions: 25, 31, 38	Acoustics Audio	1.00	3.00	2.40
4	Broadcasting & Television Sessions: 2, 8, 23, 29, 35, 41	Television Broadcast Transmission Systems Broadcast and TV Receivers	1.50	4.50	3.60
5	Circuit Theory Sessions: 3, 9, 15, 21	Network Theory Wide-Band Amplifiers Delay Lines Transistor Networks	1.25	3.75	3.00
6	Electron Devices— Engineering Management Sessions: 16, 20, 24, 26, 39	Transistors Electron Tubes Quality Control Engineering Management	1.00	3.00	2.40
7	Electronic Computers Sessions: 4, 10, 14	Electronic Computers	1.00	3.00	2.40
8	Information Theory Sessions: 22, 27, 33, 40	Noise and Modulation Information Theory	1.25	3.75	3.00
9	Instrumentation— Nucleonics— Medical Electronics Sessions: 5, 11, 17, 32, 34	Instrumentation Transistor Measurements Nucleonics Medical Electronics	1.25	3.75	3.00
10	Microwaves Sessions: 30, 36, 42	Microwave Equipment Manufacture Discontinuities & Transitions Ferrites and Detectors	1.00	3.00	2.40

Transactions of the IRE Professional Groups

Issues Recently Published

The following issues of Transactions are now available from the Institute of Radio Engineers, Inc., 1 East 79 Street, New York 21, N. Y. Prices are indicated below, with a listing of the contents of each.

CS-1, July, 1953

(Including papers presented at the Technical Conference on Communications; sponsored by the IRE Cedar Rapids Section)

Keynote Address, *Arthur A. Collins*

The Transmission of Intelligence in Typescript, *I. S. Coggeshall*

Comparative Study of Modulation Methods, *R. M. Page*

Design Trends in Communication Equipment, *L. Morgan Craft*

Voice of America and the Electromagnetic War, *George Q. Herrick*

Long-Range Communication Trends, *Murray G. Crosby*

Aspects of Naval Communications Systems, *Joseph A. Kreck*

Manufacturers' Contributions to Military Communications, *J. Ernest Smith*

Twinplex, Twinmode, and Polyplex Radiotelegraph Systems, *Christopher Buff*

Transmitting Antennas at Mackay Radio Brentwood Station, *B. Hart*

Constitution and By-Laws

Vol. AU-1, No. 4, July–August, 1953

Technical Editorial

Loudspeaker Impedance, *Vincent Salmon*

PGA News

PGA Committee Appointments, *Marvin Camras*

New Chapters

IRE-PGA Session at NEC

Technical Papers

Room Acoustics, *Hale J. Sabine*

The Uniaxial Microphone, *Harry F. Olson, John Preston, and John C. Bleazey*

PGA Institutional Listings

Vol. EC-2, No. 3, September, 1953

A Photoelectric Decimal-Coded Shaft Digitizer, *W. H. Libaw and L. J. Craig*

An Analog-to-Digital Converter, *A. D. Scarbrough*

The Univac Tube Program, *T. D. Hinkelman and M. Kraus*

Contributors

Review Section, *H. D. Huskey, Ed.*

Institutional Listings

PGAE-8, June, 1953

A Report from the Chairman, *K. C. Black*

Memorandum from the Editor, *John E. Wilkinson*

Classified Symposium on Airborne Electronics

A Discussion of United Air Lines VHF Network Developments, *K. J. Rhead*

Theoretical Performance of Airborne Moving Target Indicators, *Frank R. Dickey, Jr.*

Calendar of Coming Events

Professional Cards

PGIE-1, August, 1953

Certification of Industrial Heating Equipment, *Everett G. Henry*

The Role of Electronics in Naval Ordnance, *J. M. Bridges*

Induction Heating Generators as Production Tools in Heat Treating Operations, *Peter A. Hassell*

Electronics in the Atomic Energy Field, *V. L. Parsegian*

Machine Tool Control from a Digital-Analog Computer, *Harry W. Mergler, George J. Moshos, and Allen E. Young*

Electronic Control Circuits in the Mechanical Heart and Lung, *John R. Engstrom and Leo E. Farr, Jr.*

Vol. AP-I, No. 1, July 1953

News and Views

Contributions

Measurement of Path Loss between Miami and Key West at 3675 MC, *R. L. Robbins*

Radiation from a Vertical Electric Dipole over a Stratified Ground, *James R. Wait*

A Two-Dimensional Microwave Luneberg Lens, *G. D. M. Peeler and D. H. Archer*

The Effect of Ions on Magneto Ionic Characteristic Polarization, *William Snyder*

Communications

Symposium on Tropospheric Wave Propagation within the Horizon, *W. C. Hoffman*

Sponsoring Group	Publication	Group Members	IRE Members	Non-Members*
Communications Systems	Vol. CS-1, No. 1	$1.50	$2.25	$4.50
Audio	Vol. AU-1, No. 4	0.70	1.05	2.10
Electronic Computers	Vol. EC-2, No. 3	0.75	1.10	2.25
Airborne Electronics	PGAE-8	0.65	0.95	1.95
Industrial Electronics	PGIE-1	1.00	1.50	3.00
Antennas and Propagation	Vol. AP-I, No. 1	1.20	1.80	3.60

* *Public libraries and colleges can purchase copies at IRE Member rates.*

Professional Group News

Airborne Electronics

The name of the Professional Group on Airborne Electronics has been changed by the IRE Executive Committee at the request of the Group to Professional Group on Aeronautical and Navigational Electronics.

Electron Devices

The San Francisco Section of the Professional Group on Electron Devices met recently at Stanford University under the chairmanship of John S. McCullough. Dr. Walter Kohl of the Research Department of Stanford University presented a paper entitled "Tube Pumping and Processing Procedure for High Vacuum and Long Life." Dr. Kohl also conducted a panel discussion on this topic. Other members of the panel were R. E. Woenne of Litton Industries; G. E. Reiling of Varian Associates; and Homer Broker of Sylvania Electric Co.

Engineering Management

A. D. Arsem, General Electric Company, Syracuse, N. Y., has been appointed the new Secretary-Treasurer of the Professional Group on Engineering Management.

Vehicular Communications

The Executive Committee of the IRE has approved the establishment of the Boston Chapter of the Professional Group on Vehicular Communications. Interim officers appointed were Robert Lewis, Boston Edison Co., chairman, and Sherman M. Wolf, secretary.

Winnipeg Becomes Section

The Winnipeg Subsection of the Toronto Section has now been granted full Section status by the IRE Executive Committee. The territory of the new Section encompasses the Canadian Provinces of Manitoba and Saskatchewan.

Approval has also been given to the formation of the Buenaventura Subsection of the Los Angeles Section, to include the California Counties of Ventura and Santa Barbara. These actions bring the total number of IRE Sections to 68 and Subsections to 18.

Transistor Circuits Conference

The IRE Professional Group on Circuit Theory and the American Institute of Electrical Engineers are jointly sponsoring a Conference on Transistor Circuits, to be held on Thursday and Friday, February 18 and 19, 1954, in Philadelphia, Pa.

The Conference will include several papers discussing the representation of transistors for circuit design purposes, problems peculiar to the design of transistor circuits, and current trends in transistor circuits in both linear and pulse applications. The Conference is designed to appeal primarily to engineers working actively with transistor circuits; as a consequence, the introductory concepts of transistor circuit design and performance will not be reviewed in any detail.

Registration material for the Conference will be ready for mailing early in January, and details of the registration procedure will be announced at that time.

Report on the Activities of the IRE Professional Group on Circuit Theory

The following article was reprinted from the September 1953 issue of the Transactions of the IRE Professional Group on Circuit Theory. It is presented here as an excellent example of the manifold service which a typical Professional Group provides its members.

—*The Editor*

During the year ending 30 June 1953 the Professional Group on Circuit Theory has progressed well toward maturity. The increase in the number of its paid-up members from 419 to 2,027 is clear evidence of the basic role that circuit theory plays in the work of many IRE members—a role made possible because circuit theory offers a universal language and a set of concepts as applicable to servomechanisms as to microwave electronics. To fulfill this role, the PGCT will encourage symposia on applications of circuit theory that may originate in one field but which have general application in other fields, and will publish future issues of its TRANSACTIONS on a regular four-times-a-year basis. The success both of these symposia and of the TRANSACTIONS will require the active participation of prospective authors. It is worthwhile, therefore, to review briefly here the activities planned for the future. All members desiring to participate in these activities are encouraged to do so.

Symposia

The I.R.E. Professional Group on Circuit Theory has sponsored, or will sponsor, four symposia during the year 1953. During the I.R.E. Winter Convention, 1953, a symposium entitled "Panel Discussion on Wide-Band Amplifiers" was held. This presented five papers which summarized the broadband amplifier field from conventional amplifiers through travelling-wave-tube amplifiers. In addition to this symposium, three other sessions of contributed papers on Network Theory, Time-Domain Networks—Delay Lines, and Active Networks—Transistors, were organized for this Convention. All of these papers were published in the "Convention Record of the IRE, Part 5" which was distributed free to PGCT members.

The PGCT co-operated with the Polytechnic Institute of Brooklyn's Microwave Research Institute to present a symposium in New York on April 23rd and 24th, on "Nonlinear Circuit Analysis." During the four sessions, twenty-one papers were presented to cover theoretical and applicational topics in this field. The papers are to be published in October 1953 and PGCT members may purchase copies of the symposium proceedings at a reduced rate.

Two sessions on circuit theory were sponsored by the PGCT at the Western Electronic Show and Convention. Papers given at those sessions comprise this issue of the TRANSACTIONS. Arrangements are also being made to publish some of the papers given at the Servomechanisms Sessions in the next issue of the PGCT TRANSACTIONS.

During the National Electronics Conference, September 28–30, in Chicago, the PGCT will sponsor a symposium on Filtering. This will include two sessions covering topics on Wave Filters and Time-Domain Filtering. A list of the papers by title is given below in the report of the Chicago Chapter.

A symposium is being planned in co-operation with the Philadelphia Sections of the IRE and AIEE on the general topic of design and synthesis problems associated with active, solid-state elements. This will be a two-day symposium, held during the early part of February in Philadelphia, with advanced registration. The papers given will *not* be published in the PGCT TRANSACTIONS. However, further details will be given in the next issue.

Customary plans for the Circuit Theory Symposium and Circuit Theory Sessions sponsored by the PGCT at the 1954 IRE Convention are under way. The topic of the Symposium will be announced later.

Arrangements are also being made for the third Network Theory Symposium to be given in New York during April 1954 in co-operation with the Microwave Research Institute of the Polytechnic Institute of Brooklyn. The tentative topic of this symposium is "Information Networks" and it will examine some of the effects of Information Theory upon Network Theory, Design and Application. The arrangements for this program are being made at an early date so that as many international authorities as possible can be represented and describe their activities in this important new field. Authors who have material that they believe is suitable for presentation at this symposium should contact immediately Dr. Herbert J. Carlin, Chairman of the PGCT Symposium Committee.

Transactions

The PGCT has not hitherto published its TRANSACTIONS on a regular quarterly basis. There are, however, several good reasons why it should attempt to do so. One of the principal purposes of the TRANSACTIONS is to provide a quick and inexpensive publication medium for its members suitable for communicating not only technical information but also news items, announcements of symposia and other local and national activities. By publishing successive issues every three months, the PGCT can insure distribution of material within 2 to 5 months after it is received. This should permit a lively give-and-take reporting of work and ideas in progress which might not be feasible in the IRE PROCEEDINGS and should stimulate interest and participation in PGCT activities.

Many convention or symposium papers are never written up for publication because a short talk requires too much elaboration and extension to become easily a formal paper. However, the central ideas can often be discussed and summarized in one or two pages and informal notes of this type would be suitable for the TRANSACTIONS. Although the high standards of writing required by the IRE PROCEEDINGS must be adhered to, formality and completeness of treatment may not be needed. This will permit the dissemination among the workers in this field of new methods and mathematical tools of as yet unknown usefulness while the art is still developing. The circulation and discussion of partly formulated theories and unsolved problems can be most stimulating and worthwhile.

At the other extreme, there are papers replete with useful mathematical detail which, because of length or highly-specialized content, cannot find a suitable journal for publication. Network theorists, both here and abroad, have long felt frustrated over the lack of a publication catering to their interests. By providing such an outlet, PGCT TRANSACTIONS can serve a very useful purpose. To encourage the submission of high-grade papers and notes from abroad, complimentary copies of this and future issues will be sent to circuit-theory workers in Europe, Japan and elsewhere.

It is recognized that circuit theory is basic to most of electronics and that meritorious papers that might be published in the TRANSACTIONS should also be published in the PROCEEDINGS. *Prospective authors should clearly understand that the quick publication of their papers in the* TRANSACTIONS *does not preclude later publication of the same material in the IRE* PROCEEDINGS. In fact, the suggestions and criticisms received by an author upon preliminary publication of his paper in the TRANSACTIONS should enable him to polish and improve the paper for possible submission to the PROCEEDINGS.

All papers submitted to the PGCT will be reviewed by the Papers and Transactions Committee before being accepted for publication. This committee will recommend for publication in the PROCEEDINGS (or, possibly, for initial publication in the TRANSACTIONS with subsequent publication in the PROCEEDINGS) those papers that, in its opinion, contain important information that should be gotten before the entire IRE readership. Since the recommendations of the PGCT committee may be substituted for those of the IRE Papers Review Committee, papers thus sponsored by the PGCT receive preferred and special handling. In this manner, the PGCT can act both as a source and as a filter to insure that really valuable circuit-theory papers appear in the PROCEEDINGS, and that the high standards and value of this major institute publication are maintained in this field.

To give a coherence to the papers appearing in the TRANSACTIONS, some of the issues will be built around a central theme or topic. By planning these issues well in advance, we can commission specialists to organize and contribute papers to the issue devoted to their specialty. It is hoped that one paper of these issues will be in the nature of a survey paper with a good bibliography and that the other papers will treat the frontier work being done in this country and abroad on the different aspects of the topic. Issues currently being planned are as follows:

SERVOMECHANISMS ISSUE (Dec. 1953)—Organized by Prof. Otto J. M. Smith, Univ. of Calif., Berkeley, Calif. This issue will include papers given at the Western Electronic Show and Convention.

CIRCUIT STABILITY ISSUE (March 1954)—Organized by Prof. Sam J. Mason, Mass. Institute of Tech., Cambridge Mass.

With the advent of transistors as circuit elements, the engineer is faced with the necessity of applying his intuitions, derived from his experience with unilateral elements and single-loop feedback structures, to the design of stable circuits in which neither of these conditions is met. "Stability" can mean several different things: it can mean that the circuit parameter values do not change with time, temperature, and other factors often ignored in circuit theory (but so important in practice!). Or, it can refer to certain dynamical properties measured by Routh's and Nyquist's criteria, etc. In practice, these meanings are not unrelated for the sensitivity of an element implies something about the parameter tolerances as well as the stability margins. There appear to be a number of basic notions and questions concerning stability which are not generally appreciated. This issue will survey what is known and describe current developments and unsolved problems.

Network Approximation Issue (June 1954)—Organized by Dr. W. H. Kautz, Stanford Research Institute, Stanford, California.

This issue will include survey papers and a bibliography of the approximation problem in both the frequency and time domains. It should provide the circuit theorist with a most useful reference volume.

Nonlinear Filter Issue (Sept. 1954)—Organized by Mr. Warren D. White, Airborne Instruments Laboratory, Mineola, L. I., N. Y.

Time-Variable Networks Issue (Dec. 1954)—Organized by Dr. L. A. Zadeh, Columbia University, New York.

Authors who have material that is suitable for reporting in any one of these issues are urged to contact the organizer at the earliest possible date. Other topics being considered for future issues are Network Topology and Circuit Models of Physical Phenomena. Your editor will welcome good suggestions for other topics.

Although these issues each have a central topic, this will not exclude the inclusion of other contributed papers that have been accepted for publication in the Transactions. In each issue space will be provided for short, informal communications in the form of "letters to the editor" and discussions of other papers previously published in the Transactions or Proceedings. Contributions and communications should be sent to the Editor, preferably in duplicate and prepared in accordance with the standard practices for preparation of manuscripts and illustrations.

Committee Membership for 1953–54

Last spring, the Nominating Committee consisting of Drs. J. G. Brainerd, D. L. Trautman, Jr., and W. N. Tuttle, prepared the following slate of officers and committee chairmen for the one-year term ending 30 June 1954:

Chairman—C. H. Page, National Bureau of Standards, Washington 25, D. C.

Vice-Chairman—H. J. Carlin, Polytechnic Institute of Brooklyn, 55 Johnson Street, Brooklyn 1, N. Y.

Secretary-Treasurer—Milton Dishal, Federal Telecommunications, Inc., 500 Washington Avenue, Nutley 10, N. J.

West-Coast Representatives—D. L. Trautman, Jr., Dept. of Electrical Engineering, University of California, Los Angeles 24, Calif.; Louis Weinberg, Research and Development Labs. Hughes Aircraft Company, Culver City, Calif.

Symposium Committee—H. J. Carlin, Chairman, Polytechnic Institute of Brooklyn, 55 Johnson Street, Brooklyn 1, N. Y.

Special Problem Committee—W. E. Bradley, Chairman, Philco Corp., Tioga and C Streets, Philadelphia 34, Pa.

Section Chapters Committee—J. J. Gershon, Chairman, DeForest's Training, Inc., 2533 North Ashland Avenue, Chicago 14, Ill.

Papers and Transactions Committee—W. H. Huggins, Chairman, Air Force Cambridge Research Center, 230 Albany Street, Cambridge 39, Mass.; J. L. Bower, Electromechanical Dept., North American Aviation, Inc., 12214 Lakewood Blvd., Downey, Calif.; W. H. Kautz, Stanford Research Institute, Stanford California; Sam J. Mason, Dept. of Electrical Engineering, Mass. Institute of Technology, Cambridge 39, Mass.; Otto J. M. Smith, College of Engineering, Univ. of California, Berkeley 4, Calif.; W. N. Tuttle, General Radio Company, 275 Mass. Avenue, Cambridge 39, Mass.; L. A. Zadeh, Dept. of Electrical Engineering, Columbia University, New York 27, N. Y.

The members of the Administrative Committee are as follows:

Term Ends 30 June 54—J. G. Brainerd, R. L. Dietzold, E. A. Guillemin.

Term Ends 30 June 55—J. L. Barnes, H. J. Carlin, W. H. Huggins.

Term Ends 30 June 56—W. E. Bradley, Milton Dishal, C. H. Page.

Chicago Chapter News

The Chicago Chapter of the PGCT has arranged for a full program of fine technical sessions for this coming season and is looking forward to it with much enthusiasm. The Circuit Theory Group follows much the same plan as the other professional groups affiliated with the Chicago Section. When a paper to be presented is of interest to another group, a joint meeting is encouraged. For example, Bernard S. Parmet will present a paper on September 25th which is of interest to both the Broadcast and Television Receivers Group and our Group. The Co-ordinating Papers Chairman, Dr. Soria, immediately suggested a joint meeting which has since been arranged.

The other sessions will include such talent as Myril B. Reed, Thomas J. Higgins, Benjamin B. Bauer and others of similar caliber, all of whom can contribute much to a Circuit Theory meeting. In addition, the Chicago Chapter is sponsoring a symposium to be held at the National Electronics Conference in Chicago. The interesting program, which includes substantial contributions to the fields of Filter and Network Synthesis, is as follows:

Filters I

"An introduction to modern filter theory" by E. A. Guillemin.
"R-C active filters" by J. G. Linvill.
"Electro-mechanical filters" by S. P. Lapin.
"Geometric aspects of least-squares smoothing" by A. A. Houser.

Filters II

"The role of nonlinear filters in electronic systems" by W. D. White.
"Filtering impulses in the time domain" by A. A. Gerlach.
"Computational techniques which correlate steady state and transient response of filters" by E. A. Guillemin.
"Use of sampled functions for time domain synthesis" by W. K. Linvill.
"Potential analog methods of solving the approximation problem of network synthesis" by R. E. Scott.

Network Synthesis

"The role of analytic continuation in network synthesis" by S. Seely.
"The role of conformal transformations in network synthesis" by W. R. LePage.
"Formulation of the approximation problem" by N. Balabanian.
"Synthesis of RC shunted high-pass networks" by C. F. White.

The new officers are not only looking forward to a successful year with at least five scheduled meetings, but in addition they would like to make the symposium at the National Electronics Conference an annual event. The new officers for the 1953–54 season are:

Joseph J. Gershon, Chairman, DeForest's Training, Inc.

Edward E. Mittman, Vice-Chairman, Motorola, Inc.

D. H. Pickens, Secretary, Raytheon Mfg. Co.

Bernard S. Parmet, Meetings and Papers Committee, Motorola, Inc.

Willis J. Steen, Chairman Membership Committee, Motorola, Inc.

Lloyd E. Matthews, Publicity Committee, Zenith Radio Corp.

George H. Wise, Procedures Committee, DeForest's Training, Inc.

Lois E. Pepperburg, Jr., Past Chairman, Motorola, Inc.

Los Angeles Chapter News

At an election meeting held on 14 May 1953, the following officers were elected for the year 1953–54:

J. A. Aseltine, Chairman, Hughes Aircraft Co.

W. R. Abbott, Secretary-Treasurer, North American Aviation, Inc.

A. R. Noland, Program Chairman, Gilfillan Bros., Inc.

J. E. Jacobs, Program Chairman, Hughes Aircraft Co.

The group is planning to hold meetings at bi-monthly intervals with two speakers per meeting. The results of a questionnaire indicated that tutorial talks would be welcomed at every other meeting, and that the 7:30 P.M. meetings held at the Institute for Numerical Analysis on the UCLA Campus were satisfactory to most members. Joint meetings with the Los Angeles Section were not desired.

Technical Committee Notes

Under the chairmanship of D. C. Ports the **Antennas and Waveguides** Committee met on September 9. The Chairman reported that the Standards on Waveguides were approved by the Executive Committee on August 17 with the exception of Open Wire Transmission Line. John Ruze has accepted the job as Antennas and Waveguides Committee representative on the Annual Review Committee. The remaining work of the Antennas Committee, in addition to the preparation of Annual Review material, is to complete the definitions of waveguide component terms. Subcommittee 2.2 was requested to submit additional lists of component terms, and if possible suggested definitions for consideration at the next meeting. The work remaining for the West Coast Subcommittee 2.3 includes the preparation of a selected bibliography and preparation of standards on "Methods of Testing Waveguide Components."

The **Audio Techniques** Committee convened on September 9 under the chairmanship of C. A. Cady. The following changes in membership of the committee were announced: L. G. Runkle is to replace H. D. Harris; F. L. Hopper was appointed a new member; and W. L. Black is taking over the chairmanship of Subcommittee 3.2. H. W. Augustadt will continue as Chairman of Subcommittee 3.1. A review of ASA C16.5 Proposed Revision of Section 4.8—Calibration was made by the committee. A new proposal in Section 4.8 was adopted by the committee. The rest of the meeting was spent in a discussion on the Proposed Standard on Audio Systems and Components Excluding Recording: Methods of Measurement. A number of modifications were made.

On August 14th the **Facsimile** Committee met under the chairmanship of Henry Burkhard. A. G. Cooley presented printed copies of a mockup of the IRE Facsimile Test Chart. J. H. Hackenberg accepted the task of obtaining and preparing facsimile data for the Annual Review. In line with standardization of symbols, committee personnel are to survey components of facsimile equipment to determine whether special symbols might be needed. The committee then turned to a discussion of definitions of the 1942 Standards on Facsimile.

On September 10th the **Standards** Committee convened under the chairmanship of A. G. Jensen. The first item considered was ASA Draft Y32.2 on Graphical Symbols for Electrical Diagrams. K. E. Anspach pointed out that as the IRE and ASA proposals now stand, there is no indication that the two documents are identical. A F. Pomeroy suggested that a foreword be written in the IRE Standard covering this point. J. G. Kreer moved that a note be written by Mr. Anspach and inserted in the foreword to the IRE Standard and that IRE suggest to ASA that a corresponding note be inserted in the foreword to the IRE Standard. This motion was seconded by A. G. Clavier and adopted. Mr. Jensen suggested the chair would entertain a motion that the Committee fully appreciated the work which was put into this standard and the work of the entire Symbols Committee; and that, in particular, Mr. Pomeroy be commended for his work. Open Wire Transmission Line, which had been redefined by the Antennas & Waveguides Committee, was presented by Mr. Carter. The Standards Committee reviewed the definition but after considerable discussion it was moved that it be deleted from the Standards on Waveguides: Definition of Terms, 1953. The Executive Committee will be informed of the action taken by the Standards Committee. The next item on the agenda was a letter ballot from ASA on C42 Definitions. Mr. Cumming was to check with Frank Gaffney or Ivan Easton for their opinion on these definitions. Wayne Mason has completed his service tour overseas and is again in New York. He will attend the Standards Committee meetings in place of James Veatch who has so ably relieved him. With regard to Color Television, Mr. Cumming explained to the members present that the NTSC had established Panel 19 for the purpose of drafting working definitions and symbols for color television. The definitions have been turned over to

Continued on next page.

PUBLICATIONS OF THE IRE

The following publications are available from the Institute of Radio Engineers, Inc., 1 East 79 Street, New York 21, N. Y., at the prices listed below.

Sponsoring Group	Publications	Group Members	IRE Members	Non-Members*
Aeronautical & Navigational Electronics (Previously Known as Airborne Electronics)	Transactions PGAE-4; "The Selectivity and Intermodulation Problem in UHF and Communication Equipment" (11 pages)	$0.45	$0.65	$1.35
	Transactions PGAE-5; "A Dynamic Air-craft Simulator for Study of Human Response Characteristics" (6 pages)	.30	.45	.90
	Transactions PGAE-6; "Ground-to-Air Co-Channel Interference at 2900 MC" (10 pages)	.30	.45	.90
	Transactions PGAE-8; June 1953 Issue (25 pages)	.65	.95	1.95
Antennas and Propagation	Transactions PGAP-4; IRE Western Convention, August 1952 (136 pages)	2.20	3.30	6.60
	Transactions Vol. AP-1, No. 1; July 1953 Issue (30 pages)	1.20	1.80	3.60
Audio	Transactions PGA-5; "Design Interrelations of Records and Reproducers," by H. I. Reiskind (8 pages)	.30	.45	.90
	Transactions PGA-7; Editorials, Technical Papers and News (48 pages)	.90	1.35	2.70
	Transactions PGA-9; September-October 1952 Issue (28 pages)	.60	.90	1.80
	Transactions PGA-10; November-December 1952 Issue (28 pages)	.70	1.05	2.10
	Transactions Vol. AU-1, No. 1; Editorials, Technical Papers and News (26 pages)	.60	.90	1.80
	Transactions Vol. AU-1, No. 2; Editorials, Technical Papers and News (36 pages)	.80	1.20	2.40
	Transactions Vol. AU-1, No. 3; Editorials, Technical Papers and News (24 pages)	.80	1.20	2.40
	Transactions Vol. AU-1, No. 4; Editorials, Technical Papers and News (19 pages)	.70	1.05	2.10
Broadcast and Television Receivers	Transactions PGBTR-1; Round-Table Discussion on UHF TV Receiver Considerations, 1952 IRE National Convention (12 pages)	.50	.75	1.50
	Transactions PGBTR-2; General Color-ceiver Design Considerations and Connection of UHF & Color Adaptors to UHF Receivers (21 pages)	.60	.90	1.80
	Transactions PGBTR-3; June 1953 Issue Issue (67 pages)	1.40	2.10	4.20
Circuit Theory	Transactions PGCT-1; IRE Western Convention August 1952 (100 pages)	1.60	2.40	4.80

*** Public libraries, colleges, and subscription agencies may purchase Transactions volumes at IRE Member rates.**

PUBLICATIONS OF THE IRE, CONT.

Sponsoring Group	Publications	Group Members	IRE Members	Non-members*
Communications Systems	Transactions Vol. CS-1, No. 1; Includes papers presented at the Technical Conference on Communications (72 pages)	1.50	2.25	4.50
Electron Devices	Transactions PGED-1; Papers from IRE Conference on Electron Tube Research and IRE-AIEE Conference on Semi-conductor Research, June 1952 (32 pages)	.80	1.20	2.40
	Transactions PGED-2; Papers on Electron Devices presented at the IRE Conference on Electron Tube Research, Ottawa, Canada, June 16–17, 1952 and IRE Western Convention, Long Beach (84 pages)	1.60	2.40	4.80
	Transactions PGED-3; June 1953 Issue (24 pages)	.70	1.05	2.10
Electronic Computers	Transactions Vol. EC-2, No. 2; June 1953 Issue (27 pages)	.90	1.35	2.70
	Transactions Vol. EC-2, No. 3; September 1953 Issue (27 pages)	.75	1.10	2.25
	Review of Electronic Digital Computers, Papers and Discussions presented at the Joint AIEE-IRE Computer Conference (114 pages)	3.50	3.50	3.50
	Review of Input and Output Equipment Used in Computing Systems; Papers and Discussions presented at the Jount AIEE-IRE-ACM Computer Conference (142 pages)	4.00	4.00	4.00
	Proceedings of Western Computer Conference (231 pages)	3.50	3.50	3.40
Industrial Electronics	Transactions PGIE-1; August 1953 Issue (40 pages)	1.00	1.50	3.00
Instrumentation	Transactions PGI-2, "Data Handling Systems Symposium" IRE Western Electronic Show & Convention, California (109 pages)	1.65	2.45	4.95
Quality Control	Transactions PGQC-1, Papers presented at 1951 Radio Fall Meeting, and 1952 IRE National Convention (60 pages)	1.20	1.80	3.60
	Transactions PGQC-2; March 1953 Issue (51 pages)	1.30	1.95	3.90
Vehicular Communications	Transactions PGVC-2; Symposium on What's New in Mobile Radio (32 pages)	1.20	1.80	3.60
	Transactions PGVC-3; Theme: Spectrum Conservation, Washington, D. C. (140 pages)	3.00	4.50	9.00

* Public libraries, colleges, and subscription agencies may purchase Transactions volumes at IRE Member rates.

the Definitions Subcommittee of the Television Systems Committee for consideration. M. W. Baldwin, Jr. reported that there are 93 terms on the NTSC list, and that the Subcommittee has tentatively accepted 25 of these for inclusion on the IRE list. Chairman Jensen asked Mr. Anspach to bring the NTSC working symbols to the attention of the IRE Symbols Committee for consideration. The last item on the agenda was the consideration of C. A. Cady's letter of August 6, 1953 concerning the Proposed Revision of ASA C16.5. Section 4.8 (of this standard) dealing with Calibration of VU Meters had been brought up for reconsideration at the Audio Techniques Committee meeting held on September 9, 1953 at which time a new proposal was discussed and some slight changes made. The Standards Committee approved this new proposal with one change and it will now be presented to the Executive Committee for approval.

The **Electron Devices** Committee convened on September 11th under the chairmanship of G. D. O'Neill. Chairman O'Neill reviewed the results of the meeting of the Executive Group which met on September 10th. The following chairmen were recommended at that meeting: T. J. Henry, Subcommittee 7.1; R. B. Janes, Subcommittee 7.2; E. O. Johnson, Subcommittee 7.3; G. A. Espersen, Subcommittee, 7.5; P. A. Redhead, Subcommittee 7.6. A. E. Anderson, Subcommittee 7.7. A Chairman for Subcommittee 7.4, Tubes with Photoemission Cathodes, has not been selected. The Adhoc Committee on Reorganization of Committee 7 had given considerable thought to the revision of the 1950 standards and a discussion of the conclusion reached was given by L. S. Nergaard. R. M. Ryder commented on the 1953–54 Annual Review. Subcommittee Chairmen were requested to inform Dr. Ryder of the date of their next subcommittee meeting so that assignments of Annual Review responsibility may be made at these meetings. A short review of the status of standards in preparation was led by Mr. O'Neill.

On September 11th the **Facsimile** Committee met under the chairmanship of Henry Burkhard. Members of the committee had been asked to determine before the meeting whether special symbols might be required for facsimile equipment components. No special symbols for facsimile use were proposed. John Hackenberg asked for material on the progress of Facsimile which could be included in the Annual Review. Mr. Hackenberg discussed the preliminary test chart. The rest of the meeting was spent discussing definitions.

On September 18th the **Sound Recording and Reproducing** Committee met under the chairmanship of A. W. Friend. A. P. G. Peterson, Chairman of Subcommittee 19.1, reported work on three projects: (1) "Frequency Response"—R. E. Zenner is working on this document and it is expected that more data will be forthcoming in one or two months. (2) "Non-linear Distortion" in two parts—"Harmonic Distortion" and "Intermodulation Distortion"—Work on the first part is before the committee. The committee commended Dr. Peterson for the work in cooperation with Subcommittee 3.2 and Subcommittee 25.4. (3) "Determination of Actual Recorded Signal on Magnetic Recording Media." J. H. McGuigan could not be present but he spoke with Dr. Peterson and reported definite progress in technical survey of measurement and analyses. He expects to have data available within a few months. Lincoln Thompson, Chairman of Subcommittee 19.2 on Mechanical Recording and Reproducing, reports work in progress on a standard relating to "Disc Frequency Records," through the cooperation of Messrs. Fred W. Roberts and Theodore Lindenberg. They hope to have the material ready for presentation to the committee for the November 20th meeting. R. M. Fraser, Chairman of Subcommittee 19.3 on Optical Recording and Reproducing, reported progress in working with the SMPTE Interim Committee on Nomenclature in the development of definitions of terms used in Optical Recording and Reproducing. Eighty-one terms are now being considered. There was a discussion on material from Subcommittee 19.1 on Magnetic Recording. Dr. Friend announced the resignation from the main committee of Dr. Harry Schecter.

IRE People

Waquar Ahmed (A'41–M'49) has been appointed Professor and Head of the Electrical Engineering Department, Engineering College, Dacca, East Pakistan.

Waquar Ahmed

Born in Calcutta, India, in 1919, Dr. Ahmed received both his B.S. and M.S. degrees from the University of Calcutta. In 1947 he received the degree of Engineer (E.E.) and in 1949 the Ph.D. degree from Stanford University.

During the year 1949–50, he was associated with the research group at the High Voltage Engineering Laboratory of the General Electric Co. at Pittsfield, Mass. On his return to Pakistan in 1950 he joined the Electrical Engineering Department staff of the Engineering College at Dacca. He has been responsible for the planning and layout of the Electrical Engineering Laboratories at the college. At present Dr. Ahmed is on a visit to Australia and New Zealand, representing East Pakistan as a member of the Technical Observation Mission sent by the government of Pakistan.

Dr. Ahmed is an associate member of the Institution of Electrical Engineers, London, an associate member of the American Institute of Electrical Engineers, a member of Sigma Xi, and the American Association for the Advancement of Science. He is also a member of the Institute of Engineers, Pakistan.

John L. Dalke (A'46–SM'52) has been appointed a member of the Committee on Radio Electrical Co-ordination of the American Standards Association, representing the IRE. This committee deals with measuring radio interference of electrical components and completed assemblies of electrical equipment.

Born in Enid, Oklahoma in 1913, Mr. Dalke received his B.A. degree in 1937 from Phillips University, Oklahoma, and his M.S. degree in physics in 1939 from the University of Oklahoma. He has been affiliated with the Dept. of Terrestrial Magnetism of the Carnegie Institution of Washington, and the Naval Research Laboratory. From 1947 to 1951 he acted as project leader of four groups in the VHF Standards Section of the National Bureau of Standards Central Radio Propagation Laboratory. In 1951, Mr. Dalke was also appointed Assistant Chief of the Applied Electricity Section of the NBS.

Mr. Dalke is a member of the National Research Council Committee on Chemistry and Physics of the Conference on Electrical Insulation and is consultant to ASTM in connection with the establishment of radio frequency standards for dielectric measurements.

Rodney D. Chipp (A'34–SM'43) director of engineering for the Du Mont Television Network, has been elected president of the Technical Societies Council of New York, Inc. Representing virtually all of the engineering and scientific societies in the Greater New York area, the Council is composed of 25,000 members. Mr. Chipp, who served as director and treasurer during the past year, represents the IRE, one of the Council's 18 member societies.

Rodney D. Chipp

A native of New Rochelle, New York, Mr. Chipp attended the Massachusetts Institute of Technology. Associated with broadcasting since 1933, he has worked with the National Broadcasting Company, and was in the Radar Design Section of the U. S. Navy during the war. He joined Du Mont early in 1948 as director of engineering. Since then he has supervised the development of Du Mont's ultra-modern Tele-Centre in Manhattan and helped to construct new and enlarged facilities at WTTG, Washington, and WDTV, Pittsburgh.

Mr. Chipp is a member of the Society of Motion Picture and Television Engineers, the Association of Federal Communications Consulting Engineers, the Veteran Wireless Operators Association, the National Society of Professional Engineers, and is also an associate member of the United States Naval Institute.

The International Telephone & Telegraph Corporation has elected **Henri G. Busignies** (M'42–SM'43–F'45) a vice-president and member of the management advisory board.

H. G. Busignies

A native of Sceaux, France, Mr. Busignies received the E.E. degree from the University of Paris in 1926. In 1928 he entered the Paris Laboratories of I. T. & T. Until 1940 he traveled in Europe and Africa for the company, and in 1941 he joined the Federal Telecommunication Laboratories, a subsidiary of I. T. & T., as an executive engineer. Later he became technical director of that organization.

One of the leading authorities on radio and electronic aids to aerial navigation, Mr. Busignies is best known for his invention of the first automatic direction finder for aircraft, which has become standard equipment on all large commercial and military planes.

Mr. Busignies received the Lakhovsky award of the Radio Club of France in 1926. He was awarded the Presidential Certificate of Merit in 1948 for his work with the National Defense Research Council during World War II.

Harold W. McInnes (A'51) Studio Engineer for the New Westminster, B. C., Broadcasting Station of the International Broadcasting Co., died recently.

Mr. McInnes was born in Swanage, England, on December 6, 1917, and came to Canada in his early youth. His interest in radio engineering led him to service in the Signal Corps during the early part of the Second World War. From 1943–1946 the R.C.A.F. sent him to Radar and Radio School, and later he was a radar instructor at a navigational school. After the war he attended the British Columbia School of Science for further training in radio engineering.

In 1947 Mr. McInnes joined the IBC as a studio engineer in charge of design, installation and maintenance of studio and transmitting equipment.

Frederick G. Suffield (A'42–M'45–SM'49) has been appointed assistant to the President of the Triad Transformer Corporation, Venice, Calif.

F. G. Suffield

Born in Chicago, Ill., on October 22, 1920, Mr. Suffield has an engineering background of over fifteen years in design and administrative work. Prior to his connection with Triad, he was Manager of Engineering for Transco Products, Los Angeles, Calif., and responsible for engineering, test, inspection, patents, and quality control. He had previously been with the Los Angeles plant of RCA Victor as Manager of Engineering, and Chief Engineer for the Houston Corp. Before coming to Los Angeles in 1946, he was with Westinghouse Electric Corp. in Baltimore, Md.

Mr. Suffield is a member of the Optical Society of America, and is active in the West Coast Electronic Manufacturing Association.

IRE People

Maurice L. Levy (A'40–SM'47) has been appointed Assistant Works Manager of Emerson Radio and Phonograph Corp.


Maurice L. Levy

Mr. Levy has been in the electronics field since his graduation from Union College in 1924 with the degree of Bachelor of Science in Electrical Engineering. From 1924 to 1943 he was affiliated with the Stromberg-Carlson Co. as a design and development engineer. In 1943 he joined Emerson Radio as Chief Engineer, Special Products. From 1949 until the present he was affiliated with the Teletone Radio Corp. as Director and Special Engineer.

Mr. Levy, the inventor of many electronic circuits pertaining to radio, audio and associated equipment, and the author of many articles which have appeared in technical publications, has been active in various engineering committees of the Radio and Television Manufacturers Association.

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Walter J. Seeley (A'22–SM'46) chairman of the electrical engineering department of Duke University, has been named dean of the College of Engineering of the university. Professor Seeley will assume his new post on July 1. He has been a member of the faculty since 1925.

A native of Hazelton, Pa., Professor Seeley was graduated from the Polytechnic Institute of Brooklyn in 1917 and received the M.S. degree from the University of Pennsylvania in 1924. He also has done special work at Harvard and Columbia Universities. He taught for six years at the Towne Scientific School, University of Pennsylvania, before joining the Duke staff. He has for several years served numerous government and industrial organizations as consultant in the field of radio equipment design, street lighting, telephone installation, and electrical power problems. During both wars he served with the U. S. Navy, conducting experimental research and directing administrative and personnel work. He was named president of the Navy Ordnance Laboratory Technical Reserve in 1945. He is currently director of the College of Engineering's Research and Development Program, which makes available the University's facilities to industry and government.

Professor Seeley is a member of the American Institute of Electrical Engineers, the North Carolina Society of Engineers, and the Charlotte Engineers Club. He has been active in the IRE as the representative at Duke University and also on the Education Committee.

George M. Brown (A'42–SM'46) electronics engineer with the New York Central System of New York, died recently.

A native of Outlook, Washington, Mr. Brown was born on December 16, 1908. He received the degree of Bachelor of Science in Electrical Engineering in 1929 from Washington State College. From 1929 to 1946 he was affiliated with the General Electric Co. as test and radio engineer in the Radio Transmitter Department and the Transmitter Division of the Electronics Department. He led several special problems groups in radar development and emergency communications and equipment.

In 1946 Mr. Brown joined the New York Central System as an electronics engineer, to plan and supervise application of radio communication to railroad operations.

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E. Finley Carter (A'23–F'36) has been appointed Vice President and Technical Director of Sylvania Electric Products Inc.


E. Finley Carter

In his new capacity, Mr. Carter will furnish technical counsel to Sylvania's management and engineering groups, and will handle broad technical relations with industry, universities, the armed services, and other organizations.

A native of Elgin, Texas, and a graduate of Rice Institute, Mr. Carter served with the General Electric Company for a number of years in radio development work in the early days of radio broadcasting. After three years as Director of the Radio Engineering Division of United Research Corp., he joined Sylvania as a consulting engineer. He served successively as an engineer of the Radio Division, divisional assistant chief engineer, and Director of Industrial Relations before becoming Vice President in charge of Industrial Relations in 1945. A year later he was appointed Vice President in charge of Engineering.

Mr. Carter holds patents on a number of devices, including electronic control equipment, single frequency duplex transmission and reception systems, radio receiver systems, and vacuum tubes. He is a member of the American Institute of Electrical Engineers, the American Radio Relay League, the Illuminating Engineering Society, and Tau Beta Pi, honorary engineering society.

Otto H. Schade (M'40–SM'43–F'51) nationally known radio, TV and electronics engineer of the Tube Department of the RCA Victor Division, Radio Corporation of America, has been invested with the honorary degree of doctor of engineering by Rensselaer Polytechnic Institute. The degree was bestowed "in recognition of his part in the development of radio and television," according to the official citation.


Otto H. Schade

Born and educated in Germany, Mr Schade came to this country in 1926. Five years later he began his long association with the RCA Tube Department at its Harrison, N. J., plant. Since 1938 he has specialized in television circuits, camera tubes, and picture tubes, and for the past several years has been perfecting a unique system of universal ratings and allied electronic test equipment with which, for the first time, the quality of picture-producing instruments can be measured in objective mathematical terms.

Mr. Schade has been the recipient of many awards, among them the RCA Victor Award of Merit, the Modern Pioneers Award of the National Association of Manufacturers, and the Morris Liebmann Memorial Prize of the IRE. He is also the first recipient of the David Sarnoff Gold Medal Award of the Society of Motion Picture and Television Engineers.

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Michael J. Di Toro (A'37–SM'45) has joined the Fairchild Guided Missiles Division of the Fairchild Engine and Airplane Corporation to head electronic development in the Division's engineering department.

Dr. Di Toro holds his doctor's degree in electrical engineering from Brooklyn Polytechnic Institute with the major field of communication and the minor fields of physics and mathematics. Widely known for his work in communications and missile instrumentation, he was for a time associate director of the Microwave Research Institute of Brooklyn Polytechnic Institute. He also filled important engineering posts in several leading electronics firms.

Dr. Di Toro is the author of many technical papers, presented before major societies in his field. He is also Adjunct Professor in the Graduate Electrical Engineering Department of the Polytechnic Institute of Brooklyn where he teaches evening courses in communication theory.

Dr. Di Toro is a fellow of the Acoustical Society of America, a member of the American Physical Society, the American Institute of Electrical Engineers and the Association for Computing Machinery. He has also been elected to the honorary fraternities, Eta Kappa Nu and Sigma Xi.

IRE People

Dr. Raymond A. Heising (A'20–F'23) recently retired from the Bell Telephone Laboratories, Inc., after 39 years of service.

DR. R. A. HEISING

Dr. Heising is one of the Bell System radio pioneers. After receiving the E.E. degree from the University of North Dakota in 1912 and his Master's degree in 1914 from the University of Wisconsin, he entered their employ in July, 1914, when they initiated their work on radio and carrier communication. He participated to a major extent in all of their early radio work and in engineering the pioneer commercial trans-oceanic radio telephone circuits. He is widely known for his radio inventions, of which his best known is the constant current modulation system which made possible a transmitter simple and efficient enough to make practical the radio telephone. He is also the inventor of several other widely-used modulation systems: the constant potential system, the grid modulation system used in radio, and the rectifier modulation system, used extensively in the telephone plant. He has over one hundred United States patents, including the patent on the class C amplifier.

Dr. Heising transferred from radio to the patent department of the Laboratories in 1945 and has since been engaged in patent engineering and other patent work. He will continue in these fields as an independent consulting engineer and patent agent.

Dr. Heising was awarded the Morris Liebmann Memorial prize of the IRE in 1921. He served as president of the Institute in 1939, as treasurer from 1943–1945, and was for several terms an elected member of the Board of Directors.

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Leonard Mautner (M'46–SM'47) and **Alexander F. Brewer** (S'41–A'44–M'44–SM'48) have announced the formation of a new company, Electronic Control Systems, Inc., of which Mr. Mautner is president and Mr. Brewer is executive vice president and secretary. The company will concentrate its efforts in seeking out and solving selected problems in the fields of automatic process control and data handling. New products will be developed and possibly manufactured later on in these specialized fields.

Mr. Mautner, one of the founders of this new company, has been active in the fields of electronics, radar, television and guided missiles. He graduated from the Massachusetts Institute of Technology with a B.S. degree in electrical engineering, and later studied at the Stevens Institute of Technology as well as M.I.T. For several years he was with the U. S. Signal Corps as a radio engineer. During World War II he was associated with the Radiation Laboratory at M.I.T., and later he was in charge of a group of engineers as Radiation Laboratory Member of the Combined Research Group, Naval Research Laboratory. Following the war, Mr. Mautner was affiliated with the Allan B. DuMont Laboratory in the Television Transmitter Division, and with the Television Equipment Corp., of which he was president. Since 1950 he has been with the Hughes Aircraft Co., in charge of electronic research and development of Guided Missiles Laboratories.

He holds six circuit patents in the fields of radar and television, and has written a number of articles in these fields, as well as a textbook, "Mathematics for Radio Engineers." He is a member of Eta Kappa Nu.

Mr. Brewer, also one of the organizers of the company, received his Bachelor's and Master's degrees in electrical engineering from the California Institute of Technology and Stanford University respectively. He has been teaching and directing a wide variety of electronic work in radar, microwave techniques, relay links, and guided missiles for more than thirteen years. During World War II, Mr. Brewer participated in a number of important developments for the armed services at the Sperry Gyroscope Co. After the war he joined the technical staff of the Hughes Aircraft Co., where he became head of the missile electronics section. For the last several years, he has been in charge of Radar Systems Research.

Mr. Brewer has received a citation from the U. S. Navy Department for his work during World War II, and holds several patents in the electronic circuit and microwave fields. He has also been a member of the Advisory Council of the R. and D. Laboratories of the Hughes Aircraft Co.

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The nomination of **Donald A. Quarles** (M'41–SM'43) to be Assistant Secretary of Defense in charge of Research and Development was recently confirmed by the U. S. Senate. Mr. Quarles has resigned his post as president of the Sandia Corp., a subsidiary of Western Electric Co., to assume his new position. He had been with the Bell Telephone System for more than thirty years. From 1925 to 1952 he was with the Bell Laboratories, Inc., of which he was appointed a vice president in 1947. In 1952 he resigned this position to become president of Sandia Corp.

Succeeding Mr. Quarles at Sandia is **James W. McRae** (A'37–F'47). (See page 1197 September 1953 PROCEEDINGS.)

Gordon N. Thayer (SM'47–F'51) has been appointed to take over Mr. McRae's duties as vice president of Bell Laboratories in charge of switching and transmission development. Mr. Thayer has been affiliated with Bell Laboratories since 1930, engaging in the development of mobile radio communications and equipment. In 1952 he was named vice president in charge of the military development of the Laboratories, the position which he held until the present time.

Replacing Mr. Thayer in his former responsibilities is **William C. Tinus** (A'31–M'36–SM'43–F'51). Mr. Tinus joined the Laboratories in 1928, working in the field of mobile radio systems for civil aviation, police and military application. During World War II he was connected with various technical advisory groups for the government, and was a part-time consultant for the War Department. After the war he became responsible for several long-term developments for the armed forces at the Laboratories, and in 1951 he was made director of the military electronics department, the position which he held until the present time.

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Donald M. McNicol (A'14–M'14–F'23–L'49) consulting communication engineer and a former president of the IRE, died recently at the age of 78.

Mr. McNicol, a native of Hopetown, Ont., Canada, had been active in the field of electrical engineering since 1890. He began his career with the Western Union Co. and the Postal Telegraph Co., and by 1900 was engaged in extensive wireless research.

He was the author of many articles and papers in his field, the most widely known of his works being "Radio and Telegraphy," one of the early books on this subject. He was also the author of "American Telegraph Practice," published in 1913, which for a decade or more was the standard text-book on the subject. In 1922 he became the editor of "Telegraph and Telephone Age," and later was named assistant to the president of Radio Corporation of America. After two years with RCA he became the editorial director of "Radio Engineering" magazine, where he continued his writing on the science of communication.

Mr. McNicol was an instructor at the Teachers College of Columbia University, and a lecturer at the Sheffield Scientific School of Yale University and Cooper Union in New York.

In 1914 he became a member of the IRE, of which he was president in 1926, and a member of the board of directors for six years. Mr. McNicol was a Fellow of the American Institute of Electrical Engineers, and served for a time as chairman of the publication committee of the AIEE.

IRE People

Ralph R. Shields (M'50), formerly merchandising supervisor for the television picture tube division, has been appointed to the newly-created post of Product Sales Manager of television picture tubes of Sylvania Electric Products, Inc.

RALPH R. SHIELDS

Receiving his radio engineering degree in 1938 from Indiana Technical College, he was formerly affiliated with Dymac, Inc., as a branch manager. He also was an instructor of basic radio theory for Alfred University, Alfred, N. Y., and supervisory engineer for special studies branch with the Signal Corps Engineering Laboratories at Ft. Monmouth, N. J. and Detroit, Mich.

Mr. Shields joined the commercial engineering department of Sylvania's radio tube division at Emporium in 1948 as a senior engineer.

Mr. Shields is the author of many engineering and business paper articles on the technical and economic aspects of television servicing and servicing instruments.

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Carl E. Smith (A'30–M'39–SM'43) has announced his resignation from United Broadcasting Co. where he served in an engineering capacity since the mid-thirties and of late years as Vice President in Charge of Engineering. He and his associates have opened offices in Cleveland, Ohio, where they will now devote full time to expanding his consulting engineering work, which he has followed for the past several years in addition to his United Broadcasting Co. connection. The new organization will continue under the name of Carl E. Smith Consulting Radio Engineers.

CARL E. SMITH

Mr. Smith received his bachelor's degree in engineering in 1930 from Iowa State College. In 1932 he received his master's degree and a professional degree in 1936.

Mr. Smith is the author of numerous technical articles and books in the field of applied mathematics, radio communication, and directional antennas. He holds memberships and is on local and national committees of many scientific and engineering societies, including the American Institute of Electrical Engineers, and the Society of Motion Picture and Television Engineers. He is a registered Professional Engineer in Ohio and Washington, D. C. and has practiced as a Consulting Engineer in a number of Federal Communications Commission hearings.

Robert D. Teasdale (S'44–A'46–M'49–SM'52) has recently been appointed Assistant to the Director of Engineering and Development at Magnetic Metals Co. of Camden, N. J. In addition to administrative duties, he is directing an analytical and experimental investigation of the effectiveness of magnetic shielding for color television tubes and other components.

R. D. TEASDALE

Dr. Teasdale received his B.S. degree from Carnegie Institute of Technology, and completed his graduate work at the Illinois Institute of Technology, where he was a Swope Fellow in 1947 and held an RCA Fellowship in electronics in 1948. He served for three years as Associate Professor of Electrical Engineering at the Georgia Institute of Technology.

He is a member of Sigma Xi, American Institute of Electrical Engineers, American Association for the Advancement of Science, Eta Kappa Nu, and the Engineers' Club of Philadelphia.

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Clyde B. Trevey (A'47–M'49), Secretary-Treasurer of the Beaumont-Port Arthur Section since May 1, 1949, died recently.

A native of Cleveland, Texas, he received his education in the public schools at Cleveland and Beaumont, Texas, and later received special training in radio and electronics in the navy.

He was employed by the Magnolia Petroleum Co. as a radio operator in 1920, and held the position of communications engineer with this company at the time of his death.

During World War I Mr. Trevey enlisted in the U. S. Navy and served as a radio operator, and again in World War II he served as a radio operator and communications officer.

He was a member of the American Radio Relay League, and an amateur radio operator of long standing.

Charles W. Barbour, Jr. (S'41–A'42–M'48–SM'51) has recently been appointed Assistant Chief Engineer of Teletronics Laboratory, Inc.

A native of Portland, Me., Mr. Barbour received his Bachelor of Science degree in electrical engineering in 1941 from Northeastern University. He then became affiliated with the Submarine Signal Co., working in the field of development and design of radar indicator circuitry and radar fire control equipment. From 1946–1951 he was with the Glenn L. Martin Co. in the Radar Development Section as an electronics research specialist. He joined the Teletronics Laboratory in April, 1952.

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J. G. Rountree (A'39–M'44–SM'50) has announced the establishment of an office for the practice of consulting radio engineering.

J. G. ROUNTREE

Mr. Rountree was born in Bee County, Texas, on January 7, 1914. He received his Bachelor's degree with honors in Electronic Physics from the University of Texas in 1937, and did graduate work at Southern Methodist University in Dallas during 1944. He is a Registered Professional Engineer.

Mr. Rountree was employed in the engineering departments of several broadcast stations in Texas from 1936 to 1941. From 1941 to 1946 he was employed in the field Division of the Engineering Department of the Federal Communications Commission. In the course of that service he was attached as a civilian liaison officer to Headquarters New Orleans Air Defense Command during World War II. During 1945, he was in charge of the Montgomery, Ala., Laboratory of the Federal Communications Commission in connection with a VHF propagation survey to assist in determining the portion of the frequency spectrum to be occupied by FM broadcasting.

He joined the firm of A. Earl Cullum, Jr., Consulting Radio Engineers, in April, 1946, leaving that organization during November, 1953, in order to establish his own office as consulting engineer.

Mr. Rountree was Secretary of the Dallas-Fort Worth Section of the I.R.E. during 1945, Vice Chairman during 1946, and Chairman during 1947. During 1950 he was an industry representative on the U. S. Delegation negotiating the Cuban phase of the North American Regional Broadcasting Agreement. He is active in the field of amateur radio and has held the license for Amateur Radio Station W5CLP since 1932.

Books

Synchronisation of Reflex Oscillators by Aly H. Abdel Dayem

Published (1953) by Verlag Leeman, Zurich, Switzerland. 110 pages. Tables and figures.
Doctorate dissertation submitted to the Swiss Federal Institute of Technology.

Demands for increased microwave power at a fixed frequency have necessitated the investigation of either the parallel operation of klystrons and magnetrons or the locking of potentially high-power magnetron oscillators by the injection of a crystal-controlled signal. Investigations are currently being made in the United States of the injection locking of modulated magnetrons for use as UHF television transmitters and of the parallel operation of microwave oscillators to obtain coherent phase, equal frequency, and additive power. The doctorate thesis of A. H. A. Dayem is an unusually comprehensive dissertation on the synchronization problem of reflex klystrons which constitutes a significant contribution and should be welcomed by workers in the field.

Chapter 1 of this pamphlet discusses the synchronization of pentode oscillators through the addition of an external signal in the grid circuit. A brief review is made of previous work done in this field and relevant results obtained by different investigators. Pentode oscillators are then considered in an application in which a parallel resonant plate circuit is inductively coupled to the grid circuit. The author assumes a non-linear function between the plate current and grid voltage, the function consisting of an oscillation-starting term and an oscillation-limiting term. Both the feed-back voltage and the external synchronizing signal are contained in the grid voltage. Equations are then formulated for the determination of the node current and the power of the plate circuit. Two relations are obtained in the calculation of the steady-state amplitude of oscillation and the relative phase. The first relation, which is called the "conservation of energy" is obtained by the integration and averaging of the power equation over a complete period. This relation, therefore, involved the averaged current and voltage quantities. The second relation, called the "frequency equation," is obtained by differentiation of the power equation, and integration and averaging of the result over a complete period. This relation involves the averaged derivatives of the plate voltage and current. The significant values derived in Chapter 1 are (1) the maximum range over which synchronization can take place, and (2) the amplitude of oscillation and the phase as functions of the deviation between the circuit resonant frequency and the operating frequency, with the amplitude of the external signal as a parameter.

Chapter 2 discusses the synchronization of reflex klystron oscillators. The theory of the velocity-modulated beam is reviewed briefly and a resume is given of the assumption made in the treatment and the limitations of the idealization. A circuit arrangement is suggested for the injection of an external signal to the klystron, the external source being assumed to have higher power capacity. In the circuit analysis, the klystron cavity is represented by a parallel resonant circuit shunted by the characteristic admittance of the waveguide. This resonant circuit is driven on one side by the injected current and on the other by the modulated beam current, which depends on the terminal voltage. Because the terminal voltage is a function of both currents, a non-linear problem is again encountered. The author has used the averaging process mentioned above to obtain expressions for the amplitude and the phase of the reflex oscillator. The performance of a hypothetical klystron has been calculated, and the amplitude, phase, and power output are plotted for varying magnitudes of the external signal.

Chapter 3 analyzes the mutual synchronization of two klystrons. The circuit arrangement is considered first. The coupling network between the klystrons is replaced by a four-terminal network or by a section of line having the proper characteristic impedance and propagation constant. The entire system can be represented by two parallel tuned circuits interposed by a transmission line. The author uses the smooth-line equations to express the relationship between the grid-gap voltage and bunched current of one klystron and those of the other. The resulting equations show the relationship of the four unknowns: the amplitudes of the two oscillators, their relative phase, and the frequency of oscillation. In view of the complexity of the problem, two special cases are considered. In the first case, the power capacity of one klystron is much higher than that of the other; in the second the two klystrons are identical.

Chapter 4 discusses the synchronous parallel operation of klystrons. The general requirements of the combining network which couples the oscillators are given and a number of possible arrangements are described. In the treatment of the special "magic T," the author employs the scattering matrix method and evaluates the elements of the matrix from the terminal conditions. The proper phase of the oscillators and the length of the waveguide connecting the klystron to the coupling network are determined so that synchronization, isolation, and matching are obtained. When a parallel cascade connection of "magic-T" networks is used, the parallel operation of 2^n klystrons is suggested.

Chapter 5 contains some experimental results. A description of special apparatus and some preliminary material on the measurement of the Q-factors of the klystron cavity are included. The results of an experiment on mutual synchronization have received primary attention. The synchronous parallel operation of two klystrons has been investigated, and the test results are given. In the concluding part of the pamphlet, the experiment on the synchronization of klystrons by means of an external signal is discussed briefly.

This pamphlet is fraught with typographical errors, some occurring in the text and some in the equations. It would be desirable for the author to supply a list of errata so that the value of the paper will not be marred appreciably. The bibliography included in the pamphlet is not complete; several papers on the synchronization of oscillators published in Great Britain and in the United States have not been included.

T. S. Chen
Radio Corporation of America
Harrison, N. J.

Introductory Electrical Engineering by Willis and Chandler

Published (1952) by D. Van Nostrand Company, Inc., 250 Fourth Ave., New York 3, N. Y. 537 pages +14-page index+iv pages. 448 figures. 9×6. $7.00.
Professors Willis and Chandler are members of the staff of Princeton University.

Professors Willis and Chandler have designed this book primarily to satisfy the basic electrical engineering needs of the non-electrical engineer. This is a difficult pedogogical task because of the necessity to cover so much ground in a relatively limited time. Moreover, the authors have had to write for the inexperienced reader who is unlikely to have the opportunity to follow his introduction to electrical engineering with detailed advanced study.

The book is an excellent accomplishment of a challenging task. On the one hand, the coverage of the various topics is sufficient for the specific needs of the reader for whom it is planned. On the other, the material, particularly that on linear and non-linear circuit theory, constitutes a good foundation upon which more advanced training can be based.

The material treated is limited to basic circuit theory, electrical machinery and electrical instruments. Only one chapter, the last, is concerned with material involving electronic devices and this is limited to the important subject of rectification. It is unfortunate that space limitations made the omission of more electronics necessary. Nevertheless, the book does establish the groundwork for a survey course in electronics for non-electrical engineers.

The material throughout the book is presented clearly, in logical order and as thoroughly as the design objective of the book warrants. Illustrative diagrams and photographs are included in substantial numbers and are well-chosen to reinforce the written material. Each chapter is followed by a sizable collection of problems which have been carefully chosen to illustrate the major points discussed.

In addition to being generally excellent as a textbook for the purposes mentioned, the book is useful to the communications engineer who has occasional need of a non-detailed refresher on electrical machinery.

L. H. O'Neill
Columbia University
New York, N. Y.

Books

Essentials of Microwaves by Robert B. Muchmore

Published (1952) by John Wiley & Sons, Inc., 440 Fourth Avenue, New York 16, N. Y. 227 pages+4-page index+4-page appendix+vi pages. 201 figures. 9×6. $4.50.

Robert B. Muchmore is on the technical staff of the Research and Development Laboratories, Hughes Aircraft Co., Culver City, Calif.

This descriptive book, which expresses concepts in words rather than in mathematics, is written for both the newcomer in the field who seeks a general basic understanding of microwaves and the practicing engineer or technician who wants a brief but comprehensive review of the physical principles of microwaves.

The book fulfills the requirements of its intended readership. Muchmore manages to explain a difficult subject in easy-to-understand (mostly non-mathematical) terms, which are nevertheless technically accurate. A knowledge of low-frequency electronics is assumed.

The book includes a brief introduction (in which the microwave region is defined as that part of the electromagnetic spectrum extending from 300 to 100,000 megacycles). The author then starts with Maxwell's laws of electricity and magnetism. Vector equations are used in the discussion of these laws merely as a convenient shorthand method of writing a principle that can be lengthy when expressed in words. Principles governing wave propagation are derived from these laws, and, in subsequent chapters, are applied to waveguides, cavity resonators, microwave filters, and microwave antennas.

In the next five chapters the above principles are applied to electron devices. The author presents excellent discussions on waves and electron streams, limitations of grid-control tubes, klystrons, traveling-wave and double-stream tubes, magnetrons, and electrical noise. It is interesting to note that the subject of microwave electron tubes takes up as much as one-third of the book.

The last four chapters cover applications for microwaves to radio systems, relays, radar, and physical research, and the subject of microwave measurements.

"Essentials of Microwaves" describes with a minimum of mathematics the basic physical principles underlying the operation of all microwave devices. The author has done a very good, concise job, and the book fulfills its intended purpose authoritatively and with high technical accuracy.

Frank R. Arams
Radio Corporation of America
Harrison, N. J.

Dielectric Aerials by D. G. Kiely

Published (1953) by John Wiley & Sons, Inc., 440 Fourth Ave., New York, N. Y. 127 pages+2-page index+1-page bibliography+xii pages. 48 figures. 6¾×4¼. $2.00.

This excellent little monograph presents a review of the existing state of the art concerning dielectric aerials.

By way of introduction to the subject the characteristics of guided wave transmission along dielectric rods and tubes are presented in considerable detail. Then the several methods of deriving the radiation characteristics of dielectric rod and tube antennas are given, together with the available experimental data. The author makes a critical evaluation of the various methods of analysis and points out their probable domains of usefulness.

The mathematical sections are complete and well-written. Those having a good background in Maxwell's equations and radiation theory will have little trouble following the analysis, especially since the author supplements the mathematics with good descriptions of the physical mechanisms involved.

The author concludes with a section on other types of dielectric antennas, such as the dielectric horn and shaped dielectric rods. An excellent bibliography is included.

This book will be of value to anyone working in the antenna field.

William C. Jakes, Jr.
Bell Telephone Laboratories, Inc.
Holmdel, N. J.

Television Receiver Design: IF Stages by A. G. Uitjens

Published (1953) by the Philips Technical Library, Eindhoven, The Netherlands, 133 pages+44-page appendices+x pages. 122 figures. 6×9. $4.50.

A. G. Uitjens is an electronic tube specialist with the Philips Research Laboratories, the Netherlands.

This is the first of a series of six to eight books on television receiver design to be published by the Philips Technical Library. It is concerned with i-f amplification and the factors which influence practical design. While quite mathematical, it is filled with numerous practical conclusions derived from the calculations and should appeal to the busy design engineer. Its readability is improved by numerous graphs and diagrams, and the book adheres to an outline which permits the study of various phases of design without confusion.

Its 179 pages are a vast expansion over the material usually given this subject in text books, and it will serve as a valuable guide and reference book not only for television engineers but for anyone concerned with broad-band amplifier design in the spectrum of 10 Mc to 100 Mc.

Among the subjects treated at length are pentode stages using two terminal coupling networks. Gain and bandwidth relations are described for staggered tuned amplifiers. Distortion in double sideband and vestigial sideband systems is discussed. The analysis is repeated for four terminal coupling networks.

The subject of noise and practical limits of amplification is well covered, including many methods for improving signal to noise ratio.

Feedback is treated from knowledge and experience, and over 30 pages are devoted to this subject in a most complete fashion. A final summary is given of practical considerations which may be deduced from the theory.

Garrard Mountjoy
A. R. & T. Electronics
North Little Rock, Ark.

Television Engineering by S. W. Amos and D. C. Birkinshaw in collaboration with J. L. Bliss

Published (1953) by Iliffe & Sons Ltd., Dorset House, Stamford Street, London, S.E. 1, England. 271 pages+4-page index+23-page appendix+3-page bibliography. 188 figures. 8¾×5¼. 30 s.

This is the first volume of a series written by members of the staff of the British Broadcasting Corporation and intended primarily for the corporation's own operating and maintenance personnel.

Considered in the light of the stated objective of the series this first volume should fulfill its purpose very well. In addition it is a valuable contribution to the literature of television and should find considerable use as a television text.

Being written from the British viewpoint the American reader may encounter a slight amount of confusion from the difference in terminology but of course this is no reflection on the authors. For example, the term "frame" is used in the manner of our "field," while our "frame" is, in turn, called a "picture." Also "post sync line suppression period," while accurately descriptive, may lack some of the intimacy of our "back porch."

The book is divided into three sections: (1) fundamentals, dealing with the concept of scanning and signal waveforms; (2) television camer tubes; and (3) television and electron optics.

The section on camera tubes is a particularly good and up-to-date one, describing the various types of tubes and clearly pointing out the advantages and limitations of each.

The section on television and electron optics devotes a space equivalent to almost one-third of the book to a rather complete and conventional treatment of the fundamental optics of mirrors and lenses. While there is no question about the material or its value, this subject is so completely covered in various texts on optics that there is some question as to the value of devoting so much space to its representation in this volume. The same feeling is held to a lesser extent concerning the part of this section devoted to electron optics as such.

Taken as a whole, this is a very comprehensive volume, written in readable style. We will look forward with interest to the succeeding volumes in the series.

Leslie E. Flory
RCA Laboratories Division
Princeton, N. J.

Books

Electronique Generale by Blanc-Lapierre, Goudet, and Lapostelle

Published (1953) by Editions Eyrolles, 61 Boulevard Saint-Germain, Paris (V^e), France. 396 pages+8-page index+58-page appendix+4-page bibliography. 203 figures. 9¾×6¾. 3.208 francs.

This book deals with the physics of the electron tube. Written in French for students of the National Advanced School of Telecommunications, it has two general objectives. It establishes first the bridge between the basic laws of physics relative to the extraction of electrons out of matter and their behavior in a vacuum when subjected to the influence of fields. Secondly, it describes the basic theory and characteristics of vacuum tubes and electron devices which employ electronic conduction.

The early chapters are concerned with the basic principles of electromagnetic field theory, Maxwell's equations, fields produced by systems of charges, and elementary considerations of relativity. This is followed by a discussion of various types of vacuum pumps and gages and the techniques for the creation of high vacuums. Next is given the theory of electrons in metals, the laws of thermionic emission, practical emitters including tungsten, thoriated tungsten and oxide coated types and the characteristics of the diode and the effects of space charge. Other forms of emission such as secondary, photoelectric and cold cathode emission are discussed. The fluctuations in the plate current of electron tubes caused by the Shottky effect and the influence of space charge are described and the mathematical relationships derived.

The last part of the book covers the field of electron optics including rubber membrane, electrolytic tank and numerical methods of studying electron trajectories. Analogies to optics are drawn to describe the electrostatic and magnetic lens. Electron guns, microscopes, particle accelerators, and the effects of transit time in high frequency tubes complete the material in this book. Appendices covering the calculus of probability, statistical mechanics and space charge derivation are helpful to those who need review in these subjects.

As will be seen from the above, this book is directed to the physics rather than engineering aspects of electron tubes. In its treatment there is a certain degree of unevenness in depth. Certain parts are treated in much detail while others are given a superficial treatment. There are places where the reader feels that his reading should be accompanied by lectures to fill in gaps. Despite these few faults, however, the book is quite good in most parts and is a worthwhile addition to the reference shelf. To those potential readers who might be deterred from investigating this book further because it is written in French, this reviewer would give the reassurance that they will become accustomed to the language after a surprisingly short time.

JOHN R. RAGAZZINI
Department of Electrical Engineering
Columbia University, New York, N. Y.

Fundamentals of Electronic Motion by Willis W. Harman

Published (1953) by McGraw-Hill Book Co., Inc., 330 West 42nd St., New York 36, N. Y. 304 pages+3-page index+11-page appendix+x pages. 10 figures. 6¼×9¼. $6.50.

Here is a book which should amply justify space on the electron tube bookshelf of many people. It is the author's intent that the book should be useful for the user of electron tubes in a strictly educational sense, and for the student whose primary aim is to gain understanding. Throughout the chapters, the philosophy of analysis is stressed rather than the presentation of specialized information. No initial mathematical knowledge beyond the calculus is assumed. In reading, it would impress one as the writing of a physicist on an engineering subject or that of an engineer tending toward fundamentals rather than practice.

Chapter headings demonstrate very well this point; for example: Fields and Electrons; Motion in a Static Field; Electron Properties and Sources; Motion in a Magnetic Field; Negative and Positive Space Charge; Motions in Time-Varying Fields; Space Charge and Velocity Motion; Traveling-Wave Amplification; Traveling-Wave Magnetron Amplifiers and Oscillators; and Relativistic Electrodynamics.

The book is quite easy to read; his style is excellent, it has instructive illustrations, and it is well-interspersed with problems to test the reader on his understanding of the text.

The reviewer would recommend this book to beginners in graduate study of physics or electrical engineering and to those starting or early in a professional career of electron tube research and development.

For those more skilled, many would still find it interesting reading, although not as a point of departure for advanced work in the fields encompassed.

HAROLD A. ZAHL
Signal Corps Engineering Laboratories
Fort Monmouth, N. J.

Mathematical Physics by Donald H. Menzel

Published (1953) by Prentice-Hall, Inc., 70 Fifth Ave., New York, N. Y. 408 pages+4-page index+vii pages. 77 figures. 6¼×9¼. $11.35.

This text is properly entitled "Mathematical Physics." It differs from most theoretical physics texts in placing major emphasis on mathematical methods and tools rather than on the development of physical theories. On the other hand, it differs from mathematics texts in emphasizing vigor rather than rigor. Very little attention is paid to existence and uniqueness theorems, and problems of convergence of the various expansions are passed over lightly.

Many mathematical tools are introduced and carried far enough to give the student a familiarity and feeling of confidence in their use. For example, the student is introduced to and given an elementary working knowledge of: vector analysis, spherical harmonics, dyadics, matrices, tensors, calculus of variations, solutions of the wave equation subject to a variety of boundary conditions, eigenvalue problems, and heat flow problems.

These mathematical methods are illustrated by application to a wide variety of subjects chosen from classical and relativistic mechanics, electromagnetic theory, and electron dynamics.

A selection of problems appears at the end of each chapter. The problems have been introduced primarily to give the student exercise in the application of the mathematical tools developed in the text.

It is the opinion of the reviewer that the author has done a fine job of bringing together in a very readable form a wide selection of mathematical methods that are normally acquired by students only by taking scattered courses.

LLOYD T. DEVORE
German Electric Co.
Syracuse, N. Y.

Principles and Practices of Telecasting Operations by Harold E. Ennes

Published (1953) by Howard W. Sams & Co., Inc., 2201 E. 46th St., Indianapolis, Ind. 565 pages+26-page appendix+4-page index+vii pages. 13 figures. 6×9¼. $7 95.

This publication of 596 pages will be welcomed by those thousands of engineers and technicians who are directly connected with the installation, operation, maintenance, and repair of television equipment.

It is the second of a series of "reference handbooks" written by Harold E. Ennes for the broadcast industry. His first publication, "Broadcast Operators Handbook," was published by John F. Rider in 1947 for the AM Broadcast industry. This latest book on television practices and principles will be an indispensable reference source for technical directors, supervisors, crew chiefs, operating technicians and production personnel.

The reader will find the book clearly illustrated and the material well prepared in a straightforward, easy-to-read style. Very little knowledge of advanced theory is required for complete understanding.

The author has avoided the use of complicated manufacturer's diagrams, and has used instead only simplified diagrams to describe to the reader the functional circuitry in terms of basic theory.

The studio technician and cameraman will especially welcome the early chapters of the book covering the theory and operation of the image orthicon and ionoscope cameras, lens, synchronizing generators, camera control units, stabilizing amplifiers, film and slide projectors, and the flying spot scanner. An up-to-date review of operating techniques is also included, as well as a chapter on studio lighting and studio equipment maintenance procedures.

The remaining chapters cover a complete description of portable television field equipment and microwave relays for remote telecast. A thorough analysis of TV transmitters is given along with everyday operational procedures. Test equipment and maintenance techniques for the transmitting plant are also presented.

In summation, it can be said that the book contains a wealth of information for the operating personnel of TV stations, as well as those engaged in related technical fields, and is considered one of the most up-to-date handbooks recently released.

E. K. JETT
WMAR-TV
Baltimore, Md.

Abstracts and References

Compiled by the Radio Research Organization of the Department of Scientific and Industrial Research, London, England, and Published by Arrangement with that Department and the *Wireless Engineers*, London, England

NOTE: The Institute of Radio Engineers does not have available copies of the publications mentioned in these pages, nor does it have reprints of the articles abstracted. Correspondence regarding these articles and requests for their procurement should be addressed to the individual publications, not to the IRE.

Acoustics and Audio Frequencies 1805
Antennas and Transmission Lines 1806
Circuits and Circuit Elements 1807
General Physics 1809
Geophysical and Extraterrestrial Phenomena 1810
Location and Aids to Navigation 1812
Materials and Subsidiary Techniques .. 1812
Mathematics 1813
Measurements and Test Gear 1813
Other Applications of Radio and Electronics 1815
Propagation of Waves 1815
Reception 1815
Stations and Communication Systems .. 1816
Subsidiary Apparatus 1817
Television and Phototelegraphy 1817
Transmission 1818
Tubes and Thermionics 1818
Miscellaneous 1818

The index to the Abstracts and References published in the PROC. I.R.E., from February, 1952 through January, 1953, published by the *Wireless Engineer*, is now out of print. No further orders will be taken.

The number in heavy type at the upper left of each Abstract is its Universal Decimal Classification number and is not to be confused with the Decimal Classification used by the United States National Bureau of Standards. The number in heavy type at the top right is the serial number of the Abstract. DC numbers marked with a dagger (†) must be regarded as provisional.

ACOUSTICS AND AUDIO FREQUENCIES

534.133:534.232 **3164**
Graphical Aids in Interpreting the Performance of Crystal Transducers—W. G. Cady. (*Jour. Acous. Soc. Amer.*, vol. 25, pp. 687–696; July 1953.) When the mechanical damping of a transducer is large, as by acoustic radiation from one or both faces into a liquid or solid, the circular diagram that represents its characteristics requires special treatment. As a background for this treatment, the uses and limitations of the conventional circle for a resonator with small losses is first reviewed. The problem of the transducer with large losses is then considered with special reference to the equations and graphs for a thickness-type transducer with unsymmetrical loading. For plane-wave transducers the expressions are exact for all loads and at all frequencies, including harmonics. Either the voltage or the current may be constant. From the admittance or impedance diagrams the magnitude and phase of current, voltage, particle velocity, and vibrational amplitude at any frequency can be obtained immediately. Similar results would be found with plates in lengthwise vibration. A new type of diagram is developed for representing vibrational amplitudes. As an illustration, the case of a quartz plate radiating into three liquids of widely different acoustic properties is treated. When the load is unsymmetrical, there is no true node anywhere in the crystal except when the load is zero or infinity. There is, however, a plane of minimal vibration, the amplitude and location of which are derived. The equations indicate certain peculiar effects when the specific acoustic resistance of the medium is just twice that of the crystal.

534.231 **3165**
The Problem of the Momentum of a Sound Wave—A. Schoch. (*Z. Naturf.*, vol. 7a, pp. 273–279; March/April 1952.) The relation between the radiation pressure and momentum of a traveling sound wave is investigated; it is found that a wave packet does possess momentum, but that in a stationary wave the time average of the momentum is zero.

534.231:532.527 **3166**
The Theory of Steady Rotational Flow Generated by a Sound Field—P. J. Westervelt. (*Jour. Acous. Soc. Amer.*, vol. 25, p. 799; July 1953.) Corrections to paper noted in 1552 of June.

534.232 **3167**
Design Techniques for a High-Frequency Transducer with a Wide-Beam Searchlight Pattern—A. L. Lane. (*Jour. Acous. Soc. Amer.*, vol. 25, pp. 697–702; July 1953.) Experiments showed that a properly designed $BaTiO_3$ spherical-shell sector will give the required wide-angle radiation with negligible side lobes. Design details are discussed and the effects of various types of baffle are shown graphically.

534.232:546.431.824–31 **3168**
Electromechanical Response and Dielectric Loss of Prepolarized Barium Titanate under Maintained Electric Bias: Part 1—H. G. Baerwald and D. A. Berlincourt. (*Jour. Acous. Soc. Amer.*, vol. 25, pp. 703–710; July 1953.) For moderate driving fields, operation on the retained polarization, without additional bias voltage, is satisfactory, but at higher driving fields the dielectric losses increase inordinately and lead eventually to depolarization and loss of response. This can be remedied by application of a comparatively modest direct-voltage bias. The losses of various $BaTiO_3$ ceramics for considerable ranges of temperature, applied field and bias voltage are shown graphically. Other effects obtained with bias-voltage operation, such as increase of electromechanical coupling, are also considered.

534.26 **3169**
On the Diffraction of a Plane Sound Wave by a Paraboloid of Revolution: Part 2—C. W. Horton. (*Jour. Acous. Soc. Amer.*, vol. 25, pp. 632–637; July 1953.) Numerical values are tabulated of functions which occur in connection with the scalar wave equation in rotational paraboloidal co-ordinates. Application is made to analysis of the scattering of a plane wave by a rigid convex paraboloid of revolution. The asymptotic expansions of the scattered waves are discussed and their amplitudes are tabulated. The magnitude and phase angle of the total pressure are evaluated for points on the surface of the paraboloid. Part 1: 1047 of 1951 (Horton and Karal).

534.26 **3170**
Diffraction of Acoustic Waves at a Small Circular Aperture—T. Anders. (*Z. Phys.*, vol. 135, pp. 219–224; June 1, 1953.) The integral equations derived by Hönl (2182 of 1952) are applied to the case of a plane acoustic wave incident normally on a circular aperture in a plane screen impervious to sound. They are solved as a first approximation with the help of a suitable series representing the wave amplitude.

534.321.9:534.61 **3171**
A Thermoelectric Method of Comparing Intensities of Ultrasonic Fields in Liquids—R. B. J. Palmer. (*Jour. Sci. Instr.*, vol. 30, pp. 177–179; June 1953.) A sensitive detector causing very little disturbance of the field, and useful at high ultrasonic frequencies, is based on the rise of temperature of certain materials due to the absorption of incident radiation. A comparison is made between this device and the radiation-pressure detector. Experimental procedure and some results are given.

534.414 **3172**
The Effects of Viscous Dissipation in the Spherical Acoustic Resonator—H. G. Ferris. (*Jour. Acous. Soc. Amer.*, vol. 25, p. 799; July 1953.) Corrections to paper noted in 1564 of June.

534.612.4:621.395.61 **3173**
Absolute Calibration of Microphones at Audible and Ultrasonic Frequencies—V. Gavreau & A. Calaora. (*Ann. Télécommun.*, vol. 8, pp. 150–157; May 1953.) Two methods are discussed: (*a*) the vibrating-piston method noted in 2690 of 1952 (Gavreau and Calaora), (*b*) a reciprocity method described by Beranek (1857 of 1950), with the formula corrected to take account of the variation of acoustic impedance due to the "baffle effect" at high frequencies.

534.833.4:621.397.7 **3174**
Investigations on Sound Absorbers for Television Studios—G. Venzke. (*Tech. Hausmitt. Nordw Dtsch. Rdfunks*, vol. 5, pp. 41–46; March/April 1953.) Results of the experimental determination of sound absorption charactersitics of perforated bricks backed with rock-wool, and of rock-wool boards, are shown graphically. The design and construction of sound absorbers for the Hamburg television studios are described.

534.84 **3175**
Acoustic Design of Auditoria—P. H. Parkin and W. A. Allen. (*Nature* [*London*,] vol. 172, pp. 98–99; July 18, 1953.) A survey of design problems and their solutions, with reference to the requirements for both speech and music.

534.844.1/.2 **3176**
Reverberation Times of Some Australian Concert Halls—A. F. B. Nickson and R. W. Muncey. (*Aust. Jour. Appl. Sci.*, vol. 4, pp.

186–188; June 1953.) Measurements were made of sound-level decay rate of fortissimo chords recorded on magnetic tape from concerts broadcast from several Australian halls and from the Usher Hall, Edinburgh. The reverberation times for the Usher Hall were within 0.1 sec of those obtained by Parkin et al. (3220 of 1952). All the Australian halls have reverberation times long for their respective volumes, the Sydney hall being the worst in this respect, with an average reverberation time of 2.9 sec. This may account for complaints of the poor musical quality of the halls.

534.861.1 3177
Electro-acoustic Means for the Reproduction of Sound—F Enkel. (*Tech. Hausmitt. NordwDtsch. Rdfunks*, vol. 5, pp. 47–50; March/April 1953.)

621.395.623.7 3178
Loudspeaker Developments—P. W. Klipsch. (*Trans. I.R.E.*, vol. AU-1, pp. 16–22; May/June 1953.) The historical development of the corner type of loudspeaker unit for high-fidelity reproduction of sound is described.

621.395.623.7:534.373 3179
Acoustic Damping for Loudspeakers—B. B. Bauer. (*Trans. I.R.E.*, vol. AU-1, pp. 23–34; May/June 1953.) The transient response of loudspeakers and the cabinets in which they are fitted can be controlled by acoustic damping, which can be determined from the acoustical constants of the system by application of the results of an equivalent-circuit analysis. The performance characteristics of acoustically damped loudspeakers are largely independent of amplifier impedance. Details are given of the method of obtaining the required acoustic damping for a loudspeaker (*a*) in a flat baffle, (*b*) mounted in a cabinet.

621.395.625.3 3180
Apparatus for the Continuous Very-Long-Period Recording of Sound—A. M. Springer. (*Fernmeldetech. Z.*, vol. 6, pp. 218–219; May 1953.) An endless wire on a storage cylinder is continuously moved axially along the cylinder with the aid of a skewed auxiliary cylinder, and traverses a recording head. A wire of length 1.4 km gives a recording time of 3 hours when run at 13 cm/s.

681.85:534.851 3181
The Lateral Mechanical Impedance of Phonograph Pickups—J. G. Woodward and J. B. Halter. (*Audio Eng.*, vol. 37, pp. 19–20, 54; and pp. 23–24, 43; June and July 1953.) An outline of the experimental method of determining the dependence of pickup mechanical impedance and response on frequency is given. Curves for several types of gramophone pickup manufactured between 1901 and 1951 illustrate the improvement in performance during this period.

ANTENNAS AND TRANSMISSION LINES

621.315.2:621.396.822 3182
Noise Measurements on Telecommunication Cables—E. Widl. (*Fernmeldetech. Z.*, vol. 6, pp. 261–268; June 1953.) Circuits used in the determination of the noise sensitivity factor of long-distance telecommunication cables are given. The theory of noise investigations in artificially influenced cables has previously been given (*Frequenz*, vol. 6, p. 1; Jan. 1952.) Measurements on such cables under various load conditions are described and the results are discussed.

621.315.212 3183
Characteristics of Coaxial Cables with Disk Insulators in the Frequency Range above 1 kMc/s—G. Günther. (*Arch. Elektrotech.*, vol. 41, pp. 40–45; 1953.) The hf properties of a coaxial cable, with 13-mm inner conductor and an outerconductor 40-mm internal diameter, were investigated theoretically and experimentally at wavelengths of 10, 20 and 30 cm. For a disk separation of 40 mm, the resonance wavelength, which is equal to the critical wavelength below which losses due to the production of other wave modes increase very rapidly, is 8.3 cm. At 10-cm wavelength the attenuation due to thermal losses is 0.6% higher, the leakage attenuation 10% higher and the characteristic impedance 7% lower than in an equivalent homogeneous cable.

621.315.212 3184
Characteristics of Coaxial Cables with Helical-Strip Insulation in the Frequency Range above 1 kMc/s—H. Kaden. (*Arch. Elektrotech.*, vol. 41, pp. 45–64; 1953.) The characteristics of this type of cable, determined theoretically and experimentally, are compared with the characteristics of the disk-insulator type [*see* above]. The attenuation due to thermal losses at 10-cm wavelength is 11% higher than in a homogeneous cable, the leakage attenuation 78% higher and the characteristic impedance 18% higher, for cables with conductors of the same dimensions.

621.392:621.315.212 3185
Composite-Dielectric Coaxial Line—J. A. Kostriza. (*Elec. Commun.*, vol. 30, pp. 155–163; June 1953.) Analysis is given for wave propagation in a coaxial line in which the conductors are separated by two coaxial dielectrics of different permittivity; the possible modes are indicated and equations are derived for the cut-off frequencies. A comparison is made with the single-dielectric line as regards the ratios of the cut-off frequencies of higher-order modes. The effective permittivity of the equivalent single-dielectric line is computed from electrostatic considerations and the calculated value is verified by an experimental determination at 2.2 km for a line using air and pyralin as the two dielectrics.

621.392.09 3186
Experiments with Single-Wire Transmission Lines at 3-cm Wavelength—D. G. Kiely. (*Jour. Brit. IRE*, vol. 13, pp. 194–199; April 1953.) An account of experiments carried out in 1950 on various dielectric-covered wires. Attenuation values obtained by SWR measurements are in agreement with calculated values. A tapered cylinder of soft wood or a carbon-coated card was found suitable for loading the wire for measurement purposes. Polystyrene disks supported the stretched wire. The effect of moisture and rain on the transmission loss is considerable and limits the applications of these lines at 3-cm λ.

621.392.2 3187
The 'Exponential' Transmission Line and its Radiation Loss—G. Piefke, (*Arch. elekt. Übertragung*, vol. 7, pp. 229–235; and pp. 274–280, May and June 1953.) The "exponential" transmission line, defined by $L \propto e^{-2\beta z}$, $C \propto e^{2\beta z}$ and propagation constant $\gamma_0 = \pm i\alpha + \beta$, cannot be realized in practice. A transmission line having a similar field distribution is considered and its characteristics and field distribution are derived by a new method. Maxwell's em equations are solved for the radiation loss from this line.

621.392.21.028.4 3188
A Method of Calculating the High-Frequency Resistance of Cylindrical Conductors of Arbitrary Cross-Section—F. Lettowsky. (*Arch. Elektrotech.*, vol. 41, pp. 64–72; 1953.) An expression for the hf resistance of an infinitely long conductor is derived and applied to the Lecher-wire system and to a conductor of rectangular crosssection.

621.392.26 3189
Travelling Waves between Two Parallel Diaphragm-Loaded Reflector Planes—W. Dällenbach. (*Arch. elekt. Übertragung*, vol. 7, pp. 297–304; June 1953.) The phase velocity of waves traveling between two parallel planes can theoretically be made greater than, equal to, or less than the velocity of light in free space, by using diaphragms normal to the planes and to the direction of propagation of the waves. The theory of wave propagation in such guides with and without diaphragms is given.

621.392.26 3190
Thick Obstacles in Waveguides, and Applications—P. Chavance and P. Salort. (*Ann. Télécommun.*, vol. 8, pp. 171–183; May 1953.) The system is considered in which a rectangular conductive block is fixed by means of screws to one of the broad sides of a rectangular waveguide; such an arrangement can be used for impedance matching in several frequency channels simultaneously. From the point of view of analysis the obstacle resembles a low-*Q* resonant cavity, but simplifying approximations admissible in dealing with the latter are not valid in the present case. Charts useful for dealing with design problems for two or three channels are presented; the extension to deal with *n* channels or a wide frequency band is discussed. The measurements were made with standard French waveguide of crosssection 66.37×29.50 mm.

621.392.26 3191
A Simple Graphical Analysis of a Two-Port Waveguide Junction—J. E. Storer, L. S. Sheingold and S. Stein. (PROC. I.R.E., vol. 41, pp. 1004–1013; Sept. 1953.) Graphical analysis based on the original work of Deschamps is presented for obtaining the scattering matrix of a two-port waveguide junction from standing-wave measurements. The section may have losses, and can be asymmetrical. In addition, a method is outlined whereby the reflection coefficient of a load terminating the junction can be obtained graphically from the measurement of the reflection coefficient as seen through the junction.

621.392.26:621.392.5 3192
Wide-Band Phase-Delay Circuit—H. Sohon. (PROC. I.R.E., vol. 41, pp. 1050–1052; Sept. 1953.) If signals of the same frequency are applied at the inputs of two waveguides, the relative phase at the two outputs depends on the lengths of the waveguides and on the cut-off frequencies. The phase-delay circuit described is based on these considerations. Four relations are developed which uniquely determine the four parameters constituted by the lengths of the waveguides and the cut-off frequencies. A numerical example is worked out.

621.392.26:621.396.611.3 3193
Slot Coupling of Rectangular and Spherical Wave Guides—L. B. Felsen and N. Marcuvitz. (*Jour. Appl. Phys.*, vol. 24, pp. 755–770; June 1953.) A dominant-mode waveguide radiating through a slot into a half-space may be regarded from a network viewpoint, the half-space being represented by a number of spherical transmission lines, the waveguide feed by a uniform transmission line and the slot by a coupling network. An approximate evaluation is made of the equivalent-circuit parameters of a slot-coupled junction of a rectangular and a spherical waveguide, when the far field can be satisfactorily represented by the dominant spherical mode. The results are useful in connection with the measurement of em scattering by obstacles located in a half-space illuminated by a slot antenna.

621.396 3194
Portable Aluminium Mast—(*Wireless World*, vol. 59, p. 424; Sept. 1953.) The 200-foot mast, of Al-Si-Mg alloy, is in 8 foot 4 inch sections each weighing 110 lb. and can be erected in 8 hours by a team of six men.

621.396.67 3195

A New Solution for the Current and Voltage Distributions on Cylindrical, Elliptical, Conical or Other Axisymmetrical Antennas—O. Zinke. (PROC. I.R.E., vol. 41, pp. 1048–1049; Sept. 1953.) Abstract only. See 2437 of 1952.

621.396.67 3196

Designing Discone Antennas—J. J. Nail. (*Electronics*, vol. 26, pp. 167–169; Aug. 1953.) Discussion enabling a designer to select the least flare-angle compatible with bandwidth requirements, to determine disk size and disk-to-cone spacing for optimum matching to a 50-Ω line, and to predict radiation-pattern characteristics.

621.396.67 3197

Mutual Impedance of Rhombic Antennas Spaced in Tandem—J. G. Chaney. (*Jour. Appl. Phys.*, vol. 24, pp. 751–755; June 1953.) The mutual impedance formula for separately driven collinear standing-wave antennas may be used directly in the determination of the radiation impedance of these antennas when connected in cascade, but modifications are necessary for the case of traveling-wave antennas under similar circumstances. Formulas are derived for two identical, coaxial and coplanar rhombic antennas in tandem. These formulas are considerably simplified for the case where the antennas are closely spaced and connected in series.

621.396.67:621.317.328 3198

An Aerial Analogue Computer—W. Saraga, D. T. Hadley and F. Moss. (*Jour. Brit. IRE*, vol. 13, pp. 201–224; April 1953.) Problems of antenna-array design are discussed and a general expression for the field is derived on which the computer design can be based. A description is given of experimental apparatus, demonstrated in 1950 at the Physical Society Exhibition, by which the radiation pattern of a 2- or 3-element array is traced instantaneously on a cathode-ray tube screen. In array design, a satisfactory approximation to the required pattern is made by a direct method of curve fitting, the position of the elements, the current amplitude and phase being determined directly from the settings of the computer controls. Typical oscillograms are shown and explained. See also 1337 of 1947 (Brown and Morrison), and 282 of 1951 (Todd).

621.396.67.011.21 3199

Simplification for Mutual Impedance of Certain Antennas—J. G. Chaney. (*Jour. Appl. Phys.*, vol. 24, pp. 747–750; June 1953.) The formula for mutual impedance obtained by the generalized circuit method (1854 of 1952) is reduced to a form requiring fewer integrations when calculating the mutual impedance of various combinations of open and terminated wire antennas. The new formula is used to determine the mutual impedance of the legs of an X-type crossed-wire antenna having sinusoidal current distribution. From this result the driving point impedance of a biconical antenna can be deduced.

621.396.671 3200

A Note on the Impedance Transformation Properties of the Folded Dipole—M. Zakhaim. PROC. I.R.E., vol. 41, pp. 1061–1062; Sept. 1953.) Comment on 34 of 1951 (Guertler).

621.396.671 3201

The Theory of a Linear Antenna: Part 1—Y. Nomura and T. Hatta. (*Technol. Rep. Tohoku Univ.*, vol. 17, pp. 1–18; 1952.) The expressions for the current distribution and the field intensity along an antenna are expanded in Fourier series, and an impedance matrix is introduced to connect the coefficients of the two expansions. The current distribution and the feeding-point impedance are calculated and the results tabulated and shown graphically. A good agreement with Hallén's results (2763 of 1939) was found.

621.396.676 3202

The Fields of an Oscillating Magnetic Dipole Immersed in a Semi-Infinite Conducting Medium—J. R. Wait and L. L. Campbell. (*Jour. Geophys. Res.*, vol. 58, pp. 167–178; June 1953.) Expressions for the fields are derived for the case when the axis of the dipole is parallel to the interface between the conducting medium and the semi-infinite insulating space above it. Various special cases are discussed in detail. An estimate of the field for a frequency of 160 kc shows that the attenuation in sea-water is very great if the transmitting dipole is more than a few metres below the surface. See also 39 of January (Wait) and 2109 of July.

621.396.677 3203

Lens Aerials at Centimetric Wavelengths—J. P. A. Martindale. (*Jour. Brit. IRE*, vol. 13, pp. 243–259; May 1953.) A survey paper. Compared with systems using reflectors, lens antennas have the advantage of rear feed; scanning can be achieved by movement of the feed only, without any great change of the beam shape or loss of efficiency. Criteria are stated for assessing lens antennas, and a brief description is given of various types in use or under development.

621.396.677 3204

The Theory [of the] Convex-Waveguide Lens—T. Sakurai. (*Jour. Phys. Soc. [Japan]*, vol. 8, pp. 372–377; May/June 1953.) Theory and design data are given for a device forming part of a reflex em horn radiator. The transformation by the lens of a cylindrical wave into a plane wave is independent of frequency. An outline of the use of the lens in the construction of a very-wide-band microwave radiator is given.

621.396.677 3205

Nonresonant Sloping-V Aerial—J. S. Hall. (*Wireless Eng.*, vol. 30, pp. 223–226; Sept. 1953.) Explicit formulas are derived for the components of the distant electric field of the apex-driven sloping-V antenna, assuming uniform current distribution and infinite ground conductivity. Calculated patterns are in agreement with experiment for a typical antenna, but there is considerable vertically polarized radiation off the line of the main beam.

621.396.677 3206

The Characteristics of Parabolic Reflectors in Absorbing Media—A. Esau. (*Fernmeldetech. Z.*, vol. 6, pp. 197–201; May 1953.) Formulas are derived for the gain and the radiation characteristics of an omnidirectional dipole used with a parabolic reflector in an absorbing medium. Analogous formulas are derived for the case of the normal type of dipole. In an absorbing medium the gain decreases, the magnitudes of the subsidiary minima increase and the maxima decrease with increase of $\alpha\rho_0$, where α is the absorption coefficient of the medium and ρ_0 is the radius of the aperture of the mirror. Radiation characteristic curves are given. For experimental work at 14 cm, see 38 of 1938 and 1795 of 1939 (Brüne).

621.396.677:621.396.933 3207

Stagger-Tuned Loop Antennas for Wide-Band Low-Frequency Reception—D. K. Cheng and R. A. Galbraith. (PROC. I.R.E., vol. 41, pp. 1024–1031; Sept. 1953.) Design calculations are made for an experimental 100-kc system which consists of 12 identical small loop antennas, arranged in two groups at right angles to each other and stagger tuned to different frequencies within the required frequency band. The outputs are applied to a squaring circuit and then added in a parallel-plate summing amplifier before being passed via a grounded-grid amplifier and a cathode-follower stage to the receiver. The system has a 3-db bandwidth of 16.5 kc. An electrolyte-tank method of analysing the response of such systems is discussed in an appendix.

621.396.677.012.12 3208

A Simple Model for the Representation of the Directional Action of Two Vertical Radiators.—R. Walter. (*Tech. Hausmitt. Nordw-Dtsch. Rdfunks*, vol. 5, pp. 37–40; March/April 1953.) The intersection of a right circular cylinder with a corrugated surface representing a plane wave is shown to represent the directional pattern of radiation from two vertical radiators for any given phase and amplitude conditions. A graphical representation of a 3-dimensional model is used to obtain numerical results for particular cases.

621.396.677.1:523.72:621.396.822 3209

The Distribution of Radio Brightness over the Solar Disk at a Wavelength of 21 cm: Part 1—A New Highly Directional Aerial System—W. N. Christiansen and J. A. Warburton. (*Aust. Jour. Phys.*, vol. 6, pp. 190–202; June 1953.) Detailed description of the antenna system and method of use. A shorter account was noted in 2573 of September (Christiansen).

CIRCUITS AND CIRCUIT ELEMENTS

621.3:4.3 3210

Note on the Optimum Input-Winding Resistance of a Magnetic Amplifier employing Voltage Feedback—P. D. Atkinson. (*Elliott J.*, vol. 1, pp. 102–103; May 1953.)

621.314.3†:621.314.7 3211

Transistor-Controlled Magnetic Amplifier—R. H. Spencer. (*Electronics*, vol. 26, pp. 136–140; Aug. 1953.) A circuit is described in which the collector electrode of a transistor is connected to a winding on a toroidal core, this part of the circuit being completed via the secondary of a transformer (primary voltage 12.5v at 60 cps) and the load resistor back to the transistor base electrode. With this arrangement, output currents up to 100 ma peak can be obtained in the load for emitter input-signal currents <0.5 ma peak. Complete response to a change of input signal is obtained in one cycle of the applied alternating voltage.

621.314.7 3212

Collector-Base Impedance of a Junction Transistor—R. L. Pritchard. (PROC. I.R.E., vol. 41, p. 1060; Sept. 1953.) Comment on 874 of March (Early).

621.314.7:[621.396.645+621.318.57 3213

Transistor Circuits and Applications—G. C. Sziklai. (*Elec. Eng.*, vol. 25, pp. 358–364; Sept. 1953.) See 2583 of September.

621.316.726.078.3 3214

Theory of A.F.C. Synchronization—W. J. Gruen. (PROC. I.R.E., vol. 41, pp. 1043–1048; Sept. 1953.) The performance of an AFC system can be described in terms of three parameters: (*a*) the gain constant, (*b*) the damping ratio, and (*c*) the resonance or cut-off frequency. Using these parameters, expressions for the performance under conditions of small disturbance to the input phase and for the pull-in performance are derived, two different types of control-network transfer function being considered.

621.316.86:537.312.6 3215

The Characteristics and Applications of Thermally Sensitive Resistors or Thermistors—J. W. Howes. (*Jour. Brit. IRE*, vol. 13, pp. 228–239; April 1953.) Basic properties of thermistors are reviewed and terms used to specify their characteristics are defined. Outline descriptions are given of their applications in measurement, control and protection circuits, etc.

621.318.435.3 3216

A Range of 400-c/s and 1600-c/s Transductors for Service Use—A. G. Milnes and C. S. Hudson. (*Elec. Eng.*, vol. 25, pp. 322–326; Aug. 1953.) A survey of common transductor types is made and details are given, together with particular applications, of input-type transductors with mumetal or permalloy cores for supply voltages of 13, 15 and 50v rms, and power-type units with HCR or permalloy-F cores for supply voltages of 115 and 200v rms. All are of the automatic self-excitation type.

621.319.4 3217

Stray Capacitance with High-Permittivity Dielectrics—W. Heywang. (*Z. angew. Phys.*, vol. 5, pp. 161–163; May 1953.) Expressions are derived for the stray es field and stray capacitance of a parallel-plate capacitor. The corrections for stray capacitance of circular parallel-plate and cylindrical capacitors are determined.

621.387:621.316.721 3218

Control of Thyratrons by Small Signals—R. Bailey. (*Elec. Eng.*, vol. 25, pp. 374–377; Sept. 1953.) Variation of the phase of the control-grid voltage enables the power supplied by a thyratron to an external circuit to be varied continuously over a wide range. The results obtained with small control voltages indicate that although signals as small as 1–2 v may be permissible when the thyratron forms part of a feedback system, large signals should be used whenever possible.

621.392.26 3219

A Circular-Waveguide Magic Tee and its Application to High-Power Microwave Transmission—B. E. Kingdon. (*Jour. Brit. IRE*, vol. 13, pp. 275–287; May 1953.) The magic-T discussed comprises a circular-section waveguide with two mutually perpendicular side arms of rectangular section, spaced longitudinally at a distance λ_g; this system constitutes a pair of $H_{01}-H_{11}$ mode transformers. The device can be used as a variable power-dividing or power-combining bridge, and one of its main uses is for combining feedback power with power from the source at the input to a linear electron accelerator. When two similar sections are joined via a rotatable coupling, the resulting system is suitable for external connection via the rectangular side arms; the power-dividing ratio depends on the angle of rotation between the two sections. Other applications include use with a circular polarizer to act as a phase-shifter or variable impedance.

621.392.4 3220

A Contribution to the Theory of Nonlinar Systems—L. A. Zadeh (*Jour. Frank. Inst.*, vol. 255, pp. 387–408; May 1953.) A system of classification of nonlinear 2-terminal networks is introduced and basic properties of various classes are established. The system is such that each class in the sequence N_1, N_2, N_3 . . . contains as a member the class before it. A general nonlinear network of class N_1 is completely defined by its responses to a family of step functions with amplitudes ranging over all real values. An explicit expression is developed for the response of a class-N_1 network to a specified input. Modes of realization and characterization of networks of class N_n are outlined and a procedure for determining the optimum filter of any class is indicated.

621.392.5+621.396.615 3221

The Equivalent Q of RC Networks—P. Tenger; A. P. Bolle, (*Elec. Eng.*, vol. 25, pp. 394–395; Sept. 1953.) Comments on 2919 of October (Brown) and author's reply.

621.392.5 3222

Response Characteristics—L. Storch. (Proc. I.R.E., vol. 41, p. 1061; Sept. 1953.) Comment on 2374 of 1951 (Kenyon).

621.392.5 3223

A Note on the Analysis of Vacuum-Tube and Transistor Circuits—L. A. Zadeh. (Proc. I.R.E., vol. 41, pp. 989–992; Sept. 1953.) The setting up of node equations for a network containing one or more active elements is reduced essentially to the determination of the admittance coefficients for the passive network resulting from removal of the active elements, and adding to these the corresponding admittance coefficients for the active elements, the latter being obtained from tables given in the text. Mesh equations are obtained in an analogous way, using impedance-coefficient tables.

621.392.5 3224

Tolerance Coefficients for RC Networks—C. Belove. (*Jour. Appl. Phys.*, vol. 24, pp. 745–747; June 1953.) A method is presented for determining the effect on network design characteristics of the use of nonideal components. A set of tolerance coefficients is derived relating percentage changes of the positions of the poles and zeros of the network function to percentage changes of the network components. Changes of gain or phase are then easily calculated. An exact solution is obtainable only when the network contains at most three independent capacitors. Two theorems are proved which serve to check approximations made for more complex networks.

621.392.5 3225

Realizability Conditions for the Series-Parallel Matrix and Canonical Series-Parallel Circuits for Reactance Quadripoles—F. M. Pelz. (*Frequenz*, vol. 7, pp. 160–166; June 1953.)

621.392.5 3226

Spinor Theory of Four-Terminal Networks—W. T. Payne. (*Jour. Math. Phys.*, vol. 32, pp. 19–33; April 1953.) A spinor can be described as a geometrical object in 3-dimensional space having a magnitude (s) and three Eulerian angles. In the application of spinor theory to 4-terminal networks the four spinor components represent the complex current and complex voltage, the associated vector represents power and the direction ratio represents impedance. Applications of the spinor theory are shown, but the study is restricted to steady-state conditions. Negative resistance is not excluded from the considerations.

621.392.5 3227

The Four-Pole Transmission Matrix—S. R. Deards. (*Elec. Eng.*, vol. 25, p. 351; Aug. 1953.) Comment on 1605 of June (Hinton), and author's reply.

621.392.5 3228

The Gyrator as a 3-Terminal Element—J. Shekel. (Proc. I.R.E., vol. 41, pp. 1014–1016; Sept. 1953.) A 3-terminal gyrator, forming the nucleus of any 3-terminal network that violates the reciprocity relation, is considered. A method is developed which realizes such an element with any unilateral transducer such as a tube or transistor. The effect of loading by parallel or series admittance is investigated.

621.392.5/.6]:512.831 3229

The Algebraic Theory of Linear Transmission Networks—M. G. Arsove. (*Jour. Frank. Inst.*, vol. 225, pp. 310–318; and pp. 427–444; April and May 1953.) The theory is based on the series combination of two networks, with equal numbers of input and output terminals, to form a "semi-group." The theory is developed in a series of definitions, theorems and proofs. Fundamental properties of transmission networks are derived and principal types of network are classified. By means of a factorization theorem a simple criterion for symmetry can be derived. The necessary and sufficient conditions for the existence of a characteristic impedance are determined. The theory provides a concise definition and a method of rigorous treatment of the general transmission line.

621.392.5:621.314.25 3230

Simplified Solution of Phase-Shift Networks—R. D. Trigg. (*Elec. Eng.*, vol. 25, pp. 331–332; Aug. 1953.) The method is particularly applicable to phase-shift circuits in RC oscillators and selective amplifiers. The arbitrary initial assumption is made that all reactive network elements can be treated algebraically as resistances, i.e. as scalar quantities. This enables mesh equations to be written down and solved simply, the results being then interpreted in terms of the complex quantities involved. Three illustrative examples are worked out.

621.392.5.015.3 3231

A Simple Connection between Closed-Loop Transient Response and Open-Loop Frequency Response—J. C. West and J. Potts. (*Proc. IEE*, part II, vol. 100, pp. 201–208; June 1953. Discussion, pp. 209–212. The phase-margin concept of the characteristics of the Nyquist diagram in the vicinity of the critical point is extended to give a more generalized formula. This relates the damping of the principal oscillatory mode of a closed-loop feedback system to the shape of the Nyquist diagram. All the quantities involved can be obtained from this diagram without further mathematical analysis or graphical construction on the diagram.

621.392.5.029.64:538.614 3232

New Linear Passive Nonreciprocal Microwave Circuit Component—L. Goldstein and M. A. Lampert. (*Elec. Commun.*, vol. 30, pp. 164–165; June 1953.) Reprint. See 1265 of May.

621.392.52 3233

Termination Variation in the Constant-K Filter—S. C. Dunn. (*Wireless Eng.*, vol. 30, pp. 227–231; Sept. 1953.) The problem treated is that of finding the modification required in a conventional filter when the terminations are resistive, but otherwise quite general. The filter elements are given normalized values and, in addition, modified by factors λ_1 and λ_2 to correspond with the change in termination from equal values to those modified by factors α and β. From the expressions for the insertion transfer ratio of the original and of the modified circuit, by equating appropriate terms and solving, a diagram is constructed relating the four factors x_1, x_2, α and β. Two numerical examples illustrate the practical application of the diagram in the design of filter half-sections. Full-section and multi-section filters are treated in similar fashion, the calculations being correspondingly more complex.

621.392.52 3234

Synthesis of Narrow-Band Direct-Coupled [waveguide] Filters—H. J. Riblet. (Proc. I.R.E., vol. 41, pp. 1058–1059; Sept. 1953.) Discussion on 58 of February.

621.392.52 3235

Design of Symmetrical Bridge-Type Electrical Filters by the Operating-Parameter Theory—F. M. Pelz. (*Arch. elekt. Übertragung*, vol. 7, pp. 290–296; June 1953.) Design formulas are developed and tabulated for symmetrical low-pass filters of degrees 1, 3, 5 and 7, for attenuation characteristics with given zeros and poles. A review of the theoretical foundations is based on work by Cauer (392 of 1942) and by Darlington (1361 of 1940).

621.392.52 3236

A Unitary Design System for Band-Pass Filters of the Zobel and Laurent Types—R. C. Brandt. (*Frequenz*, vol. 7, pp. 167–180; June 1953.) A systematic representation of the properties of band-pass filters, based on the wave-parameter theory, is followed by the development of general design formulas for band-pass half-sections, including the zigzag filters of Laurent. The system is based on Cauer's classification of Q functions, supplemented by some intermediate functions.

621.392.52.029.42 3237
A Band-Pass Filter for Low Frequencies—G. W. Morris and P. G. M. Dawe. (*Electronic Eng.*, vol. 25, pp. 365–369; Sept. 1953.) Description, with circuit diagrams, of a filter with a pass band of 8–13 cps, consisting of four stagger-tuned *RC*-amplifier circuits with inputs and outputs connected in parallel by resistor networks. The filter was developed for α-band encephalography.

621.392.6 3238
Synthesis of 2*n*-Poles by Networks Containing the Minimum Number of Elements—B. D. H. Tellegen. (*Jour. Math. Phys.*, vol. 32, pp. 1–18; April 1953.) The method of Brune (1932 Abstracts, p. 280) is extended to the synthesis of passive $2n$-poles; the procedure is illustrated for $n=3$. After splitting off a series resistance, the number of elements in the $2n$-pole can be reduced, and by repeating this procedure the $2n$-pole of zero order can be realized as shown.

621.395.645:621.395.44 3239
The L3 Coaxial System: Amplifiers—Morris, Lovell and Dickinson. (*See* 3411.)

621.396.61.029.62:621.396.933 3240
High-Frequency Oscillators Designed for Regulation and Control of Aircraft V.H.F. Equipment—R. Olivier. (*Onde élect.*, vol. 33, pp. 343–346; May 1953.) Description of a quartz-controlled 75-mc fixed-frequency unit, and a 108–132-mc vfo with a frequency converter for the range 329–335 mc. A 1-mc quartz crystal provides check points for all harmonics of 1 mc in the range of the vfo.

621.396.611.1 3241
Action of an Unlimited Train of Telegraphic Signals on a Resonant RLC Circuit—J. Marique. (*HF, Brussels*, vol. 2, pp. 145–156; 1953.) The response of a series *RLC* circuit to a train of pulse signals is considered for three types of pulse: rectangular, symmetrical trapezoidal, and of sine-squared form. Analysis shows that in the steady state, whatever the degree of mistuning of the circuit with respect to the signal hf, the amplitude of the current varies continually with time. The variations are due partly to energy dissipation during the intervals between the signals, and partly to beating of the forced oscillations due to the signals with the natural oscillations of the circuit. The latter effect is particularly noticeable in a very selective circuit, but its magnitude is largely dependent on the degree of mistuning of the circuit. See also 3041 of 1952 and 1941 of July.

621.396.611.1:621.3.016.35 3242
Amplitude Stability in Oscillating Systems—N. R. Scott. (PROC. I.R.E., vol. 41, pp. 1031–1034; Sept. 1953.) As a supplement to the Kryloff and Bogoliuboff method of determining amplitude of oscillation in quasilinear systems, a method based upon energy balance is presented. From the energy-balance condition, a criterion for stability of oscillation is deduced for the case of one degree of freedom. The treatment is then generalized to systems of n degrees of freedom.

621.396.611.1:621.396.822 530.145 3243
Quantum Theory of a Damped Electrical Oscillator and Noise—J. Weber. (*Phys. Rev.*, vol. 90, pp. 977–982; June 1953.) "Field quantization is applied to an electrical oscillating circuit. Damping effects are treated by perturbation theory. Quantum effects occur both in the damping and in the noise, and are discussed in detail. . . . The vacuum fluctuations are shown to be observable in certain [low-temperature] noise experiments."

621.396.615:621.314.7 3244
Junction-Transistor Circuit Applications—P. G. Sulzer. (*Electronics*, vol. 26, pp. 170–173; Aug. 1953.) The basic circuits described include amplifiers, impedance-changing circuits, phase inverters, oscillators, multivibrators and sawtooth frequency-sweep oscillators.

621.396.615.14 3245
Self-Excitation with Disk-Seal Valves in a Grounded-Grid Circuit—E. Willwacher. (*Fernmeldetech. Z.*, vol. 6, pp. 243–249; June 1953.) A circle diagram is derived for the internal capacitive coupling between anode and cathode in a grounded-grid oscillator. The phase of the transconductance and the input admittance, resulting from the long transit times of electrons, are taken into account. Calculations for several circuits with external feedback are made with the aid of the diagram.

621.396.619.13:621.392 3246
AM-FM Analogy—H. C. Harris. (*Sylvania Technologist*, vol. 5, pp. 64–69; July 1952.) A method is described for analysing the response of a circuit to a FM signal, and for determining spectral distribution, based on considering the equivalent signal produced by a series of sequentially pulsed AM carriers whose frequencies range between the extremes of the FM deviation. The required FM response is obtained as the synthesis of the responses to these separate AM signals. Both aperiodic and periodic signals are considered. The method is particularly appropriate and gives exact results when the modulating wave form is rectangular; for other cases the results are approximate.

621.396.645 3247
The Theory and Design of Cathode-Follower Output Stages—E T. Emms. (*Elec. Eng.*, vol. 25, pp. 386–387; Sept. 1953.) Limitations imposed on the design of cathode-follower stages feeding loads with an earthy end are noted. Procedures are outlined for choice of tube for a particular service and then completing the circuit design, under the conditions that the specified maximum anode current and anode dissipation are not exceeded and that linear operation is achieved.

621.396.645:621.314.7 3248
Transistor Operation: Stabilization of Operating Points—R. F. Shea. (PROC I R.E., vol. 41, p. 992; Sept. 1953.) Correction to paper abstracted in 688 of March.

621.396.645:621.396.619.23 3249
Why Fight Grid Current in Class B Modulators?—J. L. Hollis. (*Trans. I.R.E.*, vol. AU-1, pp. 26–32; March/April 1953.) By using triode valves with low anode resistance and low amplification factor, efficient operation of audio amplifiers can be obtained without allowing the grid voltage to swing positive; grid current is thus avoided. Direct coupling may be used between the driving amplifier and a modulator operated in this way, permitting the use of a large amount of negative feedback. Measured response and distortion are presented for a modulator designed on these lines.

621.396.645.029.3 3250
A Single-Ended Push-Pull Audio Amplifier—A. Peterson and D. B. Sinclair. (PROC. I.R.E. vol. 14, pp. 118–122; Sept/June 1953.) Reprint. See 1250 of 1952.

621.396.645.029.3 3251
Analysis of a Single-Ended Push-Pull Audio Amplifier—Chai Yeh. (*Trans. I.R.E.*, vol. AU-1, pp. 9–19; March/April 1953.) See 2613 of September.

621.396.645.35 3252
Coupling of Cathode Followers in D.C. Amplifiers—L. A. Vallet-Cerisier. (*Électronique [Paris]*, no. 78, pp. 22–27; May 1953.) A symmetrical phase-reversal circuit is described which, together with screen-coupled cathode-follower stages, has resulted in the development of an amplifier operated from a single 250v source, giving a gain of 60 db and having a flat response up to 20 kc. The level of the fluctuation-noise voltage is almost too low to be measurable.

621.396.645.371.081.75 3253
Harmonic Distortion and Negative Feedback—F. G. Kerr and S. Uminski. (*Wireless Eng.*, vol. 30, pp. 232–233; Sept. 1953.) Comments on 2278 of August (Rowlands) and author's reply.

GENERAL PHYSICS

530.145.7 3254
Accuracy of Perturbation Calculated from Inaccurate Unperturbed Wave Function—A. Rahman. (*Physica*, vol. 19, pp. 377–384; May 1953.)

535.37:527.52 3255
Excitation of Luminescence by Variable Electric Fields. Primary Effect—G. Destriau. (*Jour. Phys. Radium*, vol. 14, pp. 307–310; May 1953.) Reply to Herwelly's criticisms (1644 of June), and description of further experiments showing clearly that luminescence due to glow discharge can be distinguished from luminescence induced by an electric field.

535.37:621.32 3256
Electroluminescence: a New Source of Light—G. Destriau. (*Bull. Soc. franç. élect.*, vol. 3, pp. 381–387; June 1953.) A review of developments since the discovery of the phenomenon by the author in 1936, and an account of recent experimental work. See also 110 of 1949, and 1341 of 1951 (Payne et al.).

537.224 3257
Fundamentals in the Behavior of Electrets—W. F. G. Swann. (*Jour. Frank. Inst.*, vol. 255, pp. 513–530; June 1953.) Further mathematical development. For previous work see 608 of 1951 and back reference.

537.311.4 3258
The Resistance of an Imperfect Contact between Two Metals. Comparison with Experimental Results for Thin Granular Films—N. Nifontoff and M. Perrot. (*Compt. Rend. Acad. Sci. [Paris]*, vol. 237, pp. 228–231; July 20, 1953.) See also 2628 of September (Nifontoff).

537.311.4:537.315 3259
A Simple Varying-Capacitor Method for the Measurement of Contact Potential Difference in High Vacuum—H. P. Myers. (*Proc. Phys. Soc.*, vol. 66, pp. 493–499; June 1953.) Apparatus based on Kelvin's original method and suitable for use at a pressure of 10^{-8} mm Hg is described. The value found for the contact-potential difference between Cu and Ag films evaporated on to w sheets was 0.28 ± 0.03v, the Ag being positive with respect to the Cu.

537.311.4:537.315:546.289 3260
On the Changes in Contact Potential Difference of a Germanium Rectifier during the Electrical Forming—T. Niimi. (*Jour. Phys. Soc. [Japan]*, vol. 8, pp. 324–330; May/June 1953.)

537.52 3261
Breakdown of a Gas subject to Crossed Electric Fields—W. A. Prowse and P. E. Lane. (*Nature [London]*, vol. 172, pp 116–117; July 18, 1953.) Experiments with various gases show that breakdown in a resonator subjected to 1-μs voltage pulses with a repetition frequency of 10^{10}/sec is not helped by application of alternating fields, of frequency 1, 3 or 10 mc, perpendicular to the main field, even when such fields are only a little below the value at which they would cause breakdown if acting alone.

537.523 3262
Formative Time-Lags in the Electrical Breakdown of Gases—J. Dutton, S. C. Haydon and F. L. Jones. (*Brit. Jour. Appl. Phys.*, vol. 4, pp. 170–175; June 1953.) The time rate of growth of ionization currents in a uniform field greater than that corresponding to the static sparking potential is investigated theoretically. Curves showing the dependence of the

formative time lag on overvoltage are given, with an example of their use in the elucidation of secondary ionization processes operative in the breakdown mechanism.

537.525 3263
Microwave Technique for Studying Discharges in Gases—M. A Lampert and A. D. White. (*Elec. Commun.*, vol. 30, pp. 124–128; June 1953.) Experiments were made with a neon-filled tube inserted through a "pancake" waveguide (internal height 1 mm), the variation of the discharge dc due to the rf field being observed on a cro for various relative positions of tube and guide. The frequency used was about 5 kmc and the rf power < 100 mw.

537.525:621.316.721:535.215 3264
The Control of Self-Maintained Discharge Currents by Illumination of the Cathode—W. Kluge. (*Z. angew. Phys.*, vol. 5, pp. 173–177; May 1953.) The discharge characteristics of neon-filled Ni/cs and Al/K photocells, illuminated with a Hg-discharge lamp, were obtained experimentally. The magnitude of the controllable current in the Townsend discharge space depends on the illumination of the cathode, the driving potential applied and the value of the stabilizing resistance used.

537.527.2 3265
Discharge between Positive Point and Plane in Compressed Air—M. Toitot and A. Boulloud. (*Compt. Rend. Acad. Sci.* [*Paris*], vol. 237, pp. 322–323; July 27, 1953.) At gas pressures of several tens of atmospheres, the spark discharge from a point may be preceded by relatively large currents, which are due either to the corona effect or to a dark discharge resulting from the emission from the cathode.

537.531.8+535.215 3266
Electron Emission from Metals as an After-Effect of Irradiation—K. Seeger. (*Z. Phys.*, vol. 135, pp. 152–162; June 2, 1953.) The emission of electrons from metals was measured after irradiation with X rays, ultraviolet rays and visible rays and after glow-discharge had taken effect. The dependence of the secondary emission on the wavelength of the incident radiation, and on the structure of the metal surface, was investigated. The time and temperature relation is independent of the manner of excitation, which may even be produced by mechanical means. The magnitude of the secondary emission depends on the state of oxidation of the surface. It is further discussed, how far the secondary emission depends on the nature of the metal or the nature of the surrounding gas. The work function of electrons after irradiation is also considered.

537.533:539.232 3267
Surface Films and Field Emission of Electrons—F. L. Jones and C. G. Morgan. (*Proc. Roy. Soc. A*, vol. 218, pp. 88–103; June 9, 1953.) The mechanism of cold emission of electrons from surfaces covered with a tarnish film, under electric fields of the order of 10 kv/cm, was investigated. The results obtained are consistent with the view that the electrons are extracted from the metal substrate by the high electric field set up across the thin surface film when covered with a layer of positive ions.

537.567 3268
Transmission of Radio Waves through Highly Ionized Gases—P. Verzaux. (*Jour. Phys. Radium*, vol. 14, pp. 310–316; May 1953.) Preliminary theoretical discussion of the effect of highly ionized media on the transmission of em waves, with special reference to the possible use of centimeter waves in the study of the intense thermal ionization produced in a gas subject to high-pressure shock waves.

538.56:535.42 3269
Intensity and Polarization of Electromagnetic Waves diffracted at a Slit: Part 2—H. Hönl and E. Zimmer. (*Z. Phys.*, vol. 135, pp. 196–218; June 2, 1953.) Diffraction of electromagnetic waves at a slit is investigated under the supposition that the electric field vector is perpendicular to the slit edges (magnetic case). This supplements the investigation of the same problem for the case where the electric field vector is parallel to the slit edges (electric case) [2183 of 1952 (Groschwitz and Hönl)]. The combination of both cases makes it possible to calculate the intensity and polarization of the wave field for incident polarized and unpolarized radiation. In the case of very narrow slits, to which the Fresnel-Kirchhoff theory is no longer applicable, the electric component normal of the slit edges is determinative for the diffracted field.

538.566:535.42 3270
The Diffraction of Electromagnetic Waves at a Conducting Circular Disk and at a Circular Aperture in a Conducting Plane Screen—W. Andrejewski. (*Z. angew. Phys.*, vol. 5, pp. 178–186; May 1953.) Numerical results of calculations based on the rigorous theory of diffraction of Meixner and Andrejewski (2767 of 1950) are given. These describe the characteristics of diffracted waves in the near and far fields and are valid when the circumference of the disk and the wavelength are of comparable magnitude. The methods of approximation commonly used are critically examined.

541.183.26:539.234:546.74 3271
Sorption Properties of Thin Nickel Films—W. Scheuble. (*Z. Phys.*, vol. 135, pp. 125–140; June 2, 1953.) The sorption of O and H by Ni films is studied. Oxygen sorption, which is much greater than that of hydrogen, takes place in two stages: (*a*) instantaneous covering of the film by a monatomic layer, (*b*) gradual penetration of the oxygen atoms into the film. The quantity of sorbed oxygen is independent of the gas pressure but depends on temperature. Oxygen-covered Ni films have catalytic reactions with hydrogen; on the other hand, hydrogen films have no effect on the sorption of oxygen.

GEOPHYSICAL AND EXTRATERRESTRIAL PHENOMENA

523.72 3272
Distribution of Radio Brightness on the Solar Disk at 9.35 kmc/s—I. Alon, J. Arsac and J. L. Steinberg, (*Compt. Rend. Acad. Sci.* [*Paris*], vol. 237, pp. 300–302; July 27, 1953.) Observations during the first six months of 1953, made with interferometer equipment, confirm the results obtained at the annular eclipse of Sept. 1, 1951 (Boston et al, 1282 of 1952) concerning the increased brightness at the edge of the disk. Further observations will be required to determine whether the radio brightness increases at first uniformly from the center and then more rapidly to a maximum near the edge, or whether there is a secondary maximum at the center.

523.72:621.396.822 3273
Asymmetry in the Decimetre-Wave Radiation from the Sun—E. J. Blum. (*Compt. Rend. Acad. Sci.* [*Paris*], vol. 237, pp. 135–137; July 15, 1953.) Data obtained in Australia at the eclipse of November 1, 1948, and in Khartoum, at the eclipse of February 25, 1952, are adduced in support of the conclusion that radiation from the quiet sun at wavelengths around 50 cm is best accounted for by a model sun having an equatorial-axis/polar-axis ratio of 3:2. See also 2786 of 1952 (Blum et al.) and back reference.

523.72:621.396.822:621.396.621 3274
Radio-Noise Receivers—Steinberg. (*See* 3402.)

523.746"1953.01/.03" 3275
Provisional Sunspot-Numbers for January to March, 1953—M. Waldmeier. (*Jour. Geophys. Res.*, vol. 58, p. 266; June 1953.)

523.75:550.385 3276
Solar-Flare Effects and Magnetic Storms—D. van Sabben. (*Jour. Atmos. Terr. Phys.*, vol. 3, pp. 270–273; June 1953.) In the years 1949–1951 there appeared to be no increase in storm probability after the occurrence of a solar-flare effect, except perhaps in the probability of severe magnetic storms.

523.755:621.396.822 3277
Thermal Emission from the Solar Corona in the Wavelength Range 10 cm-10 m—A. Reule. (*Z. Naturf.*, vol. 7a, pp. 234–247; March/April 1952.) Calculations are made of the sun's radiation for various models of the corona. A method is developed for determining the temperature of the corona from the measured intensity distribution over the solar disk. Radiation from the corona may introduce appreciable irregularities in the intensity distribution. Failure to take account of deviations from radial symmetry may lead to incorrect interpretation of results; Stanier's conclusions (1401 of 1950) may be affected in this way.

523.854:621.396.822 3278
An Investigation of the HII Regions by a Radio Method—P. A. G. Scheuer and M. Ryle. (*Mon. Not. R. Astr. Soc.*, vol. 113, pp. 3–17; 1953.) The distribution of brightness near the galactic plane was determined from measurements made with a radio interferometer at 81.5 mc and 210 mc. The results obtained are discussed.

550.38:621.317.353.2 3279
The Harmonic Analysis of the Earth's Magnetic Field, for Epoch 1942—H. Spencer Jones and P. J. Melotte. (*Mon. Not. R. Astr. Soc. Geophys. Suppl.*, vol. 6, pp. 409–430; June 1953.) There is no evidence of a dipole field of external origin greater than 0.1% of the field of internal origin. The intensity of the latter is, at present, decreasing by about 5% per century. The geomagnetic poles have a westerly drift of 4.5° per century; the mean position of the north magnetic pole at present is 73.5°N, 100°W.

550.38"1953.01/.03" 3280
Cheltenham Three-Hour-Range Indices K for January to March 1953—R. R. Bodle. (*Jour. Geophys. Res.*, vol. 58, p. 266; June 1953.)

550.384:525.35 3281
On Variations of the Geomagnetic Field, Fluid Motions, and the Rate of the Earth's Rotation—E. H. Vestine. (*Jour. Geophys. Res.*, vol. 58, pp. 127–145; June 1953.) Full paper. See 1338 of May.

550.384.3:931: 3282
The Magnetic Secular Variation in New Zealand—A. L. Cullington. (*N. Z. Jour. Sci. Tech.*, vol. 33, Sec. B, pp. 355–372; March 1952.) An account is given of the work on secular variation from 1941 to 1950. The observations are tabulated and the results are presented in the form of isoporic charts for each magnetic element.

550.385:523.72:621.396.822]:621.396.11 3283
Relationship between Radio-Propagation Disturbance, Geomagnetic Activity and Solar Noise—D. van Sabben. (*Jour. Atmos. Terr. Phys.*, vol. 3, pp. 194–199; May 1953.) Data on ionospheric disturbance of radio communication between New York and Amsterdam during the years 1948–1950 are compared with geomagnetic character figures. A general correlation is established, the maximum radio disturbance showing a mean time lag of 7 hours behind the maximum geomagnetic disturbance. Investigation of the relation between solar rf radiation and geomagnetic storms showed that a marked increase of the radiation on at least one of the frequencies 80, 175 and 200 mc occurred at some time during the five

days preceding a storm, except in the case of recurrent storms.

550.385"1952.10/1953.03" 3284

Principal Magnetic Storms [Oct. 1952–March 1953]—(*Jour. Geophys. Res.*, vol. 58, pp. 267–269; June 1953.)

550.386"1952.10/12" 3285

International Data on Magnetic Disturbances, Fourth Quarter, 1952—J. Bartels and J. Veldkamp. (*Jour. Geophys. Res.*, vol. 58, pp. 261–265; June 1953.)

551.51 3286

Physical Properties of the Atmosphere between ~80 km and ~250 km—H K. Kallmann. (*Jour. Geophys. Res.*, vol. 58, pp. 209–217; June 1953.) The calculated values of temperature, pressure, molecular weight, density and particle concentration are in fair agreement with available experimental results.

551.510.3:535.325 3287

The Constants in the Equation for Atmospheric Refractive Index at Radio Frequencies—E. K. Smith, Jr., and S. Weintraub. (PROC. I.R.E., vol. 41, pp. 1035–1037; Sept. 1953.) See 1990 of July.

551.510.535 3288

Ionospheric Disturbance Forecasting—L. H. Martin. (*Jour. Brit. IRE*, vol. 13, pp. 291–301; June 1953.) Causes and effects of solar-flare disturbances, prolonged periods of low-layer absorption, and ionospheric storms, are reviewed. In an examination of the bases for predicting ionospheric storms, sunspot classification is explained and the correlation of ionospheric storms with solar-flare effects, geomagnetic data and "precursor" disturbances in high latitudes is discussed. In general the accuracy of predictions 10 days in advance is 65–80%. Disturbance ratings used in the storm warning service are given and methods of prediction adopted during sunspot-maximum and sunspot-minimum periods are outlined.

551.510.535 3289

A Note on the 'Sluggishness' of the Ionosphere—E. V. Appleton. (*Jour. Atmos. Terr. Phys.*, vol. 3, pp. 282–284; June 1953.) By analogy with the lr circuit, a "time of relaxation" $\frac{1}{2}\alpha N$, analogous to a time constant, is obtained from the equation for the variation of ionization, where N is the electron density and α the recombination coefficient. Two methods of determining αN are described and its value is calculated for the D, E, F_1 and F_2 (winter) layers. Although the value of N varies by a factor of over 100, αN is constant within a factor of about 5. This result may be interpreted as indicating either that α must fall steadily from the D to the F_2 layer, or that the physical process of electron disappearance is not merely one of attachment.

551.510.535 3290

Method of Determining the True Height of the Ionospheric Layers, taking account of the Effect of the Geomagnetic Field: Part 1—Application of an Approximate Expression for the Refractive Index (Ordinary-Ray Case)—E. Argence and M. Mayot. (*Jour. Geophys. Res.*, vol. 58, pp. 147–165; June 1953. In French.) Expressions are derived for the characteristic parameters of an ionospheric region, assuming a parabolic law for the ionization. The values of the virtual heights of the F_2 layer, for frequencies in the range 1.45–3.80 mc are calculated and compared with the observed heights and those calculated by Appleton's method. The correction term in the expression for the thickness of the layer shows that the effect of the geomagnetic field is such as to reduce the value of the thickness. Numerical results are in good agreement with the corrections indicated by Shinn and Whale (1405 of 1952.)

551.519.535 3291

Dynamic Probe Measurements in the Ionosphere—G. Hok, N. W. Spencer and W. G. Dow. (*Jour. Geophys. Res.*, vol. 58, pp. 235–242; June 1953.) Measurements made during a v-2 rocket flight showed a rapid rise of probe current between 90- and 105-km height, which indicated a positive-ion/electron density ratio of approximately 10:1.

551.510.535 3292

Nature and Origin of Sporadic E Regions as observed at Different Hours over Calcutta—B Chatterjee. (*Jour. Atmos. Terr. Phys.*, vol. 3, pp. 229–238; June 1953.) Typical results of the experimental determination of the variation of the reflection and transmission coefficients of the E_s region are shown graphically, and a statistical study is made of the variation of echo amplitude. The amplitude distribution of E_s echoes from a thin layer is of the Gauss type, that from an ion cloud of the Rayleigh type, while, in general, both the steady and the scattered reflection components are present to give a Rice type of distribution (2168 of 1945). The results of observations made in the early morning, at sunrise, in the afternoon and during thunderstorms are discussed and several ionizing agents are suggested.

551.510.535 3293

Ionospheric Storms in the Auroral Zone—T. Nagata and T. Oguti. (*Rep. Ionosphere Res. [Japan]*, vol. 7, pp. 21–28; March 1953.) The values of f_0F_2 observed at College, Alaska, are statistically analyzed. When the F_2 layer in the auroral zone is sunlit, the value of f_0F_2 usually begins to decrease just after the commencement of a geomagnetic storm. This is attributed to an expansion of the layer due to heating caused by impinging corpuscles. When the F_2 layer is in darkness, an increase of f_0F_2 is observed.

551.510.535 3294

Travelling Disturbances in the Ionosphere—R. E. Price. (*Nature, [London]*, vol. 172, pp. 115–116; July 18, 1953.) Pulse measurements at 5.8 mc have been made during the past three years at Perth, Western Australia, using Munro's method (2504 of 1950). Results agree in general with those of Munro. The velocities observed ranged between 5 and 20 km/min. The direction of travel in summer lies between 0° and 90° S of E and in winter between 0° and 60° E of N, with a rapid change-over in the equinoctial months.

551.510.535 3295

F-Region Triple Splitting—G. R. Ellis. (*Jour. Atmos. Terr. Phys.*, vol. 3, pp. 263–269; June 1953.) "Measurements of the direction of arrival of Z echoes have been made at Hobart, Tasmania. The results indicate that F-region triple splitting is caused by back scattering from a rough layer. The directions observed are consistent with the assumption that reflection at the Z level occurs when the angle of incidence is such that the wave normal becomes parallel to the geomagnetic field at the ordinary level of reflection."

551.510.535 3296

Continental Maps of Four Ionospheric Disturbances—R. S. Lawrence. (*Jour. Geophys. Res.*, vol. 58, pp. 210–222; June 1953.) The changes with time of the geographical distribution of f_0F_2 deviations from normal are shown.

551.510.535 3297

Sweep-Frequency h't Measurement of the Ionosphere—Y. Nakata, K. Kan and H. Uyeda. (*Rep. Ionosphere Res. [Japan]*, vol. 7, pp. 1–6; March 1953.) Continuous records of F_2-layer heights were obtained with equipment covering the frequency band 1.8–3.5 mc in 10 seconds. The records show marked discontinuities at approximately 1700,0000 and 0400 local time. The corresponding graphs of F_2-layer heights for several stations in Japan, and of the geomagnetic variations at one station, are shown.

551.510.535 3298

A Consideration of the Mechanism of Electron Removal in the F_2 Layer of the Ionosphere—T. Yonezawa. (*Rep. Ionosphere Res. [Japan]*, vol. 7, pp. 15–20; March 1953.) The transformation of atomic ions into molecular ions by a transfer of charge and the subsequent recombination of molecular ions with electrons are considered theoretically. Such a mechanism may possibly explain the attachment type of electron removal, but the theory fails to give the value of the attachment coefficient and of its variation with height.

551.510.535:537.568 3299

The Collision Frequency of Electrons in the Ionosphere—M Nicolet. (*Jour Atmos. Terr. Phys.*, vol. 3, pp. 200–211; May 1953.) Theoretical analysis indicates that the electron collision frequency in the ionosphere depends on the concentration of neutral particles in the D and E regions and on the electron concentration in the F region. Any atmospheric model for the region above the E layer should not, therefore, be based on the frequency of electron collisions with neutral particles.

551.510.535:550.384/.385 3300

Diurnal and Storm-Time Variations of Geomagnetic and Ionospheric Disturbance—R. P. W. Lewis and D. H. McIntosh. (*Jour. Atmos. Terr. Phys.*, vol. 3, pp. 186–193; May 1953.) Analysis of records obtained at Abinger and Slough during a period of 46 months shows the diurnal variations to be very complex, with significant differences dependent on season and on activity level. The 24-hour component is important in both geomagnetic and ionospheric phenomena, but a 12-hour component is found only in ionospheric f_0F_2 disturbance. The storm-time variations of f_0F_2 and of horizontal magnetic force H are statistically closely linked.

551.510.535:550.384/.385 3301

The Morphology of the Ionospheric Variations associated with Magnetic Disturbance: Part 1—Variations at Moderately Low Latitudes—D. F. Martyn. (*Proc. Roy. Soc. A.* vol. 218, pp. 1–18; June 9, 1953.) Graphs of the ionospheric variations with local time and with storm time at Watheroo, Canberra and Washington are given. The local-time variations are mainly diurnal; the storm-time variations are appreciable for about three days after the commencement of the magnetic storm, and the initial shape of the curve depends on the local time of the commencement. A theory of these variations is developed. All ionospheric variations due to magnetic disturbance are attributed to the es field produced by the intense impressed current system in the auroral regions. See also 1673 of June.

551.510.535:550.384 3302

An Ionospheric-Disturbance Index—J. M. Bullen. (*N. Z. Jour. Sci. Tech.*, vol. 33, Sec. B, pp. 348–354; March 1952.) A three-hourly index I, with a range 0-9, based on the variation of the critical frequency and the height of the F_2 layers, has been developed. A positive correlation of ~ 0.6 was found between the Lincoln (N. Z.) I-indexes and the Amberley (N. Z.) geomagnetic K-indexes for the period between October 1949 and September 1950. The seasonal variation of the correlation between the I and K indexes was investigated and a comparison with radio disturbance conditions made.

551.510.535:550.385 3303

On the Variation of the F_2 Layer accompanying Geomagnetic Storms—K. Sinno. (*Rep. Ionosphere Res. [Japan]*, vol. 7, pp. 7–14; March 1953.) The universal-time dependent and local-time dependent parts of the variations of f_0F_2 and $h'F_2$ during geomagnetic storms have been calculated from data for several widely separated stations. The local-time variations appear to be due to the S_D current associated with the storm. No indication of a moving disturbance from the auroral zone was found.

551.510.535:550.385 3304
Storm Phenomena in the Ionosphere—E. V. Appleton. (*Arch. elekt. Übertragung*, vol. 7, pp. 271–273; June 1953. In English.) Recent advances in our knowledge of F_2-layer ionospheric perturbations accompanying a magnetic storm are summarized. The diurnal control is shown and differences between phenomena at high, medium and low latitudes are noted. For medium latitudes the effect of a storm is to exaggerate the geomagnetic distortion of the F_2 layer already present. See also 2308 of August (Appleton and Piggott.)

551.510.535:621.396.812 3305
Investigation of Ionospheric Absorption—S. J. Estrabaud. (*Electronic Eng.*, vol. 25, p. 395; Sept. 1953.) Comment on 1680 of June (Jenkins and Ratcliff) and authors' reply.

551.594.21:621.396.9 3306
Radar Echoes associated with Lightning—V. G. Miles. (*Jour. Atmos. Terr. Phys.*, vol. 3, pp. 258–262; June 1953.) Echoes from thunderstorms overhead and from distant storms were observed using 500-kw, 1.9-μs radar pulses operating on a wavelength of 10 cm. The echoes from a storm overhead frequently occur in pairs, corresponding to reflections from cloud layers at different heights.

551.594.5 3307
Orientations of Auroral Displays in West-Central Canada—R. E. Jensen and B. W. Currie. (*Jour. Geophys. Res.*, vol. 58, pp. 201–208; June 1953.) A seasonal variation of orientation was found by statistical analysis of observations made at Saskatoon in 1949–1951.

551.594.5 3308
Radio Reflections from Aurora—B. W. Currie, P. A. Forsyth and F. E. Vawter. (*Jour. Geophys. Res.*, vol. 58, pp. 179–200; June 1953.) Echoes, at 56 and 106 mc, were observed when the auroral form exhibited some ray structure and then only from parts of the aurora at elevations $<15°$ above the horizon. No echoes were recorded at 3 kmc. The 106-mc echoes occur most frequently within the auroral zone, the 56-mc echoes some distance south of it. It is suggested that echoes arise by critical reflection from centers of high electron density, $1.4\times10^8/\text{cm}^3$ for 106-mc echoes and $4\times10^7/\text{cm}^3$ for the 56-mc echoes.

551.594.5 3309
Scale-Height Determinations and Auroras—D. R. Bates and G. Griffing. (*Jour. Atmos. Terr. Phys.*, vol. 3, pp. 212–216; May 1953.) The method hitherto used for determining scale heights from auroral luminosity curves is shown to be invalid. The possibility of protons being responsible for the production of auroras is considered.

551.594.52(99) 3310
The Southern Auroral Zone as Defined by the Postion of Homogeneous Arcs—F. Jacka. (*Aust. Jour. Phys.*, vol. 6, pp. 219–228; June 1953.)

LOCATION AND AIDS TO NAVIGATION

526.94:621.396.9 3311
Nonquantized Frequency-Modulated Altimeter—H. P. Kalmus, J. C. Cacheris and H. A. Dropkin. (*Jour. Res. Nat. Bur. Stand.*, vol. 50, pp. 215–221; April 1953.) A frequency shifter, connected between the microwave FM oscillator feeding the transmitting antenna and the mixer of the receiver, makes continuous altitude measurement possible. The theory of operation is given and three types of the instrument are described. Experimental results, shown graphically, indicate that linear operation down to 10 feet is possible. A suitable frequency shifter for microwave equipment, utilizing a gyrator of the ferrite type, is described in an appendix.

621.396.9:551.578.1 3312
Radar Observations of Rain at Sydney, New South Wales—G. A. Day. (*Aust. Jour. Phys.*, vol. 6, pp. 229–239; June 1953.) Observations made at 9.1-cm wavelength are described and a correlation between the type of rain echo and weather conditions is established.

621.396.932/.933 3313
Latest Developments of the Decca Navigation System—P. Giroud and A. Gayffier. (*Onde élect.*, vol. 33, pp. 300–308; May 1953.) The service area and error curves are shown for the French Decca chain to be brought into service in 1953. The operation of the Mark VII receiver and route tracer for aircraft use are described.

621.396.932/.933 3314
Rana Radio-Navigation Equipment—É. Honoré and É. Torcheux. (*Onde élect.*, vol. 33, pp. 319–327; May 1953.) Considerable advantages are claimed for the system, which was first demonstrated in 1952. In its simplest form an installation comprises a "free" transmitter radiating on two frequencies F_1 and F_2 near 1600 kc, a "slave" transmitter on frequencies 40 cps above F_1 and 40 cps below F_2, and a control receiver connected by land line to the slave transmitter for frequency control. In a mobile receiver, measurement is made of the phase difference between the two 40-cps beat notes. With each transmitter radiating on four different frequencies, three signals for phase comparison are derived, providing three degrees of sensitivity in position determination. A description is given of various units of the equipment.

621.396.933 3315
Distance Measuring Equipment D.M.E.—F Penin and G Phélizon. (*Onde élect.*, vol. 33, pp. 309–318; May 1953.) Illustrated description of direct-reading equipment produced in France. Results of tests show the accuracy of the system to be within about ±250 m at distances up to 260 km.

621.396.933 3316
Regional-Control Radar Equipment at Orly—P. Bouvier. (*Onde élect.*, vol. 33, pp. 328–336; May 1953.) Description of 10-cm equipment for moving-target indication now being installed. Altitude range is 10 km and extreme horizontal range 150 km.

621.396.933 3317
Telecommunications and Radio Aids in Civil Aviation—(*See* 3419.)

621.396.933:621.396.677 3318
Stagger-Tuned Loop Antennas for Wide-Band Low-Frequency Reception—Cheng and Galbraith. (*See* 3207.)

MATERIALS AND SUBSIDIARY TECHNIQUES

621.396.933.4:373.62 3319
Training Apparatus for Air-Traffic Control by Radar—(*Engineering*, [*London*], vol. 175, pp. 572–574; May 1953.) Apparatus is described which produces artificially, by means of an electromechanical system, aircraft traces on a ppi display screen. Block diagrams are given. The heading, rate of turn, and airspeed of four aircraft may be regulated from a remote-control box and the effect of wind simulated. The pulse width, antenna beam width and speed of rotation can also be adjusted.

533.5 3320
Methods of Obtaining High Vacuum by Ionization. Construction of an 'Electronic Pump'—H. Schwarz. (*Rev. Sci. Instr.*, vol. 24, pp. 371–374; May 1953.) English version of 2011 of July.

535.37 3321
Field Emission of Crystal Phosphors—M. Ueta. (*Jour. Phys. Soc.* [*Japan*], vol. 8, pp. 429–431; May/June 1953.) The relation between emission intensity and applied potential for Zn_2SiO_3-Mn and ZnS-Cu phosphors is shown graphically.

535.37:546.471.61:537.533.9 3322
The Decrease of Luminescence resulting from Irradiation by Electrons—K. H. J. Rottgardt. (*Naturwissenschaften*, vol. 40, pp. 315–316; June 1953.) The observed change in luminescence of ZnF_2 screens wtih the number of the impinging electrons is in close agreement with a relation given by Broser & Warminsky (1371 of May). The electron traps produced cause the transition of electrons, without radiation, from the conduction band into the filled band.

537.224 3323
Plastic Electrets and their Applications—H. H. Wieder and S. Kaufman. (*Elec. Eng. N.Y.*, vol. 72, pp. 511–514; June 1953.) See 2025 of July.

537.311.33 3324
Space-Charge-Limited Emission in Semiconductors—W. Shockley and R. C. Prim. (*Phys. Rev.*, vol. 90, pp. 753–758; June 1, 1953.) For an *n-i-n* structure comprising a plane parallel layer of intrinsic semiconductor between two layers of *n*-type material, an expression for current density is derived which is analogous to Child's law for thermionic emission. In obtaining this expression, both diffusion and dependence of mobility on field have been neglected. An exact solution can be given for both *n-i-n* and *p-i-p* structures, when drift velocity is proportional to field.

537.311.33 3325
Preparation and Properties of Arsenide Semiconductors—F. Gans, J. Lagrenaudie and P. Seguin. (*Compt. Rend. Acad. Sci.* [*Paris*], vol. 237, pp. 310–313; July 27, 1953.) Arsenides of Ga and In were prepared by heating the constituent materials to controlled temperatures in an evacuated fused-quartz tube. The arsenide of Ga has good rectifying properties. One *n*-type sample would rectify up to 20 or 25 v. Another sample showed *p*-type rectification. The material is also photoconductive, with a sharp cut-off near 1.1 μ.

537.311.33:[546.28+546.289 3326
Mobility of Holes and Electrons in High Electric Fields—E. J. Ryder. (*Phys. Rev.*, vol. 90, pp. 766–769; June 4, 1953.) Pulse measurements of conductivity were made for *n*- and *p*-type Ge filaments at temperatures of 77°K, 193°K, and 298°K, and for *n*- and *p*-type Si filaments at 298°K. The specimens consisted of short slender filaments with two relatively massive ends. At 298°K, the observed critical field, above which mobility varies as $E^{-1/2}$, E being the electric field, is 0.9 kv/cm for *n*-type Ge, 1.4 kv/cm for *p*-type Ge, 2.5 kv/cm for *n*-type Si, and 7.5 kv/cm for *p*-type Si. Results of conductivity measurements on an *n*-type Ge specimen at 20°K are also given.

537.311.33:546.28 3327
Energy-Band Structure in Silicon Crystal—E. Yamaka and T. Sugita. (*Phys. Rev.*, vol. 90, p. 992; June 1, 1953.) Calculations for the lowest three energy levels give results in agreement with experimental values. See also 421 of February (Holmes).

537.311.33:546.289 3328
High-Field Mobility in Germanium with Impurity Scattering Dominant—E. M. Conwell. (*Phys. Rev.*, vol. 90, pp. 769–772; June 1, 1953.) Discussion of Ryder's results (3326 above) for an n-type Ge specimen at 20°K. A combination of impurity scattering and lattice scattering accounts semiquantitatively for the observed variations in mobility, provided the rate of energy loss in collisions is greater by a factor of about 9 than that given by theory based on the assumption of spherical surfaces of constant energy.

537.311.33:546.289 3329
Space-Charge Limited Hole Current in Germanium—G. C. Dacey. (*Phys. Rev.*, vol. 90, pp. 759–763; June 1, 1953.) The theory of Shockley & Prim (3324 *above*) is extended to the case of high electric fields, and the corresponding expression for current density is deduced. Experiments on Ge at 77°K give results in good agreement with theory, when recently determined values of mobility, critical field and "punch-through" voltage are used.

537.311.33:546.289 3330
Forming of Germanium Surfaces—R. Thedieck. (*Z. angew. Phys.*, vol. 5, pp. 163–165; May 1953.) The barrier potential distribution in the vicinity of a forming crater was determined experimentally. A continuous p-type surface was obtained from n-type Ge by repeated point forming so that the formed areas overlapped. The barrier potential of the formed surface was independent of the shape and material of the metal point contact used in the forming process.

537.311.33:546.289:621.314.7 3331
Mechanism of Point-Contact Transistors—R. Thedieck. (*Z. angew. Phys.*, vol. 5, pp. 165–166; May 1953.) The thickness of the p-type layer and that of the barrier layer obtained by the point-contact forming of n-type Ge (3330 above) were estimated as about 14μ and $<2\mu$ respectively. A 2-point-contact transistor with characteristics similar to those of a p-n-p-junction type was produced.

537.311.33:621.314.7 3332
***p-n* Junction revealed by Electrolytic Etching**—E. Billig and J. J. Dowd. (*Nature*, [*London*], vol. 172, p. 115; July 18, 1953.) The specimen is immersed in a suitable electrolyte, which has an inert electrode as cathode and the n-type region as anode. A current of about 1 ma/mm² maintained for 1–2 minutes etches the n-type region sufficiently to reveal the potential barrier. The method is also applicable to n-p-n specimens. This type of etching is much less effective than a strong chemical etch in improving the rectifying properties of the junction.

537.581:537.311.32:546.28 3333
Electrical Resistivity and Thermionic Emission of Silicon—L. Esaki. (*Jour. Phys. Soc. Japan*, vol. 8, pp. 347–349; May/June 1953.) Experimental investigation in the range 1100–1350°C.

538.221 3334
Developments in Sintered Magnetic Materials—J. L. Salpeter. (PROC. I.R.E., vol. 14, pp. 105–118; June 1953.) A review of ferromagnetic theory underlying the development of materials such as ferroxcube and ferroxdure.

538.221 3335
A Neutron Diffraction Study of Magnesium Ferrite—L. M. Corliss, J. M. Hastings and F. G. Brockman. (*Phys. Rev.*, vol. 90, pp. 1013–1018; June 15, 1953.) Application of a strong magnetic field enables the coherent scattering to be separated into its nuclear and magnetic parts. The magnetic scattering is in good agreement with the Néel model of ferrimagnetism. Analysis of the nuclear scattering gave a value of 0.88±0.01 for the degree of inversion and 0.381±0.001 for the u space group parameter.

538.24:538.662 3336
The Temperature Dependence of the Spontaneous Magnetization in an Antiferromagnetic Single Crystal—N. J. Poulis and G. E. G. Hardeman. (*Physica*, vol. 19, pp. 391–396; May 1953.)

538.662 3337
Condition for Vanishing Spontaneous Magnetization below the Curie Temperature—K. F. Niessen. (*Physica*, vol. 19, pp. 445–450; May 1953.) Theory is given of a method of determining the temperature T_0 at which the spontaneous magnetization of a particular spinel structure vanishes. A condition is derived for the extreme case where T_0 coincides with the Curie temperature; this condition can be applied to experiments for finding the ratio of mutual interactions of magnetic ions.

538.662 3338
On the Temperature Sensitivity of Special Magnetic Materials—T. A. Heddle. (*Brit. Jour. Appl. Phys.*, vol. 4, pp. 161–166; June 1953.) A survey of thermomagnetic materials sensitive in the range −60°C to +120°C. Applications of these materials in temperature-sensitive and compensating devices are considered.

539.23:537.311.31 3339
Complement to the Paper on the Variation of the Electrical Resistance of Very Thin Metal Films as a Function of Applied Potential—J. Romand, R. Aumont and B. Vodar. (*Compt. Rend. Acad. Sci.* [*Paris*], vol. 237, pp. 33–35; July 6, 1953.) Complementary to 2535 of 1950 (Vodar and Mostovetch). Further experiments on evaporated Pt films, using Aumont and Romand's sensitive null detector (2726 of September), confirm the previous results, but suggest that theory will probably have to be developed for films of thickness such that the space occupied by aggregates is not negligible.

539.231:537.311.31/.32 3340
Conducting Films on Glass—(*Elec. Rev.* [*London*], vol. 152, pp. 1069–1072; May 8, 1953.) The development of the cathodic sputtering process at the National Physical Laboratory for the preparation of oxide and low-resistance Au films on glass is reviewed. The thickness of the Au films is about 25×10^{-8} in. and test samples have been operated with a dissipation of 3kw/ft² without failure. Possible applications of such films to prevent electrification of the glass in sensitive electrical instruments, as fixed resistors in radar circuits, and in fluorescent lamps and Hg-vapor rectifiers are noted.

546.28+546.289+546.832 3341
The Isotopic Constitution of Silicon, Germanium, and Hafnium—J. H. Reynolds. (*Phys. Rev.*, vol. 90, pp. 1047–1049; June 15, 1953.)

546.28 3342
Electron-Spin Resonance in a Silicon Semiconductor—A. M. Portis, A. F. Kip, C. Kittell and W. H. Brattain. (*Phys. Rev.*, vol. 90, pp. 988–989; June 1, 1953.)

546.289 3343
Solute Distribution in Germanium Crystals—W. P. Slichter and E. D. Kolb. (*Phys. Rev.*, vol. 90, pp. 987–988; June 1, 1953.)

546.289:[535.32+535.34 3344
The Optical Constants of a Single Crystal of Germanium—D. G. Avery and P. L. Clegg. (*Proc. Phys. Soc.*, vol. 66, pp. 512–513; June 1, 1953.)

621.314.632.1:537.312.6 3345
The Temperature Dependence of the Zero-Bias Resistance of Cuprous-Oxide Rectifiers—A. Okazaki, H. Tubota and H. Suzuki (*Jour. Phys. Soc.* [*Japan*], vol. 8, pp. 431–432; May/June 1953.) The mobility of current carriers in Cu_2O, in the range 250°–400°K, was determined from measurements of the zero-bias resistance. Landsberg's formula (3472 of 1952) was used. Comparison is made with results obtained by other workers from Hall-effect measurements.

MATHEMATICS

511:53:621.39 3346
Radio Technology and the Theory of Numbers—V. van der Pol. (*Jour. Frank. Inst.*, vol. 255, pp. 475–495; June 1953.) The application of results of the theory of numbers to problems in physics and radio technology is illustrated by particular examples.

516.6:517.7 3347
Some Coordinate Systems Associated with Elliptic Functions—P. Moon and D. E. Spencer. (*Jour. Frank. Inst.*, vol. 255, pp. 531–543; June 1953.) Results are given of a study of cylindrical and rotational co-ordinate systems based on elliptic-function transformations. The six transformations listed are the ones most likely to be of practical utility.

519.272.119 3348
On a Class of Stochastic Operators—L. A. Zadeh. (*Jour Math Phys.*, vol. 32, pp. 48–53; April 1953.) A relation between autocorrelation functions, and a product relation for autocorrelation functions, are derived for given linear stochastic operators.

681.142 3349
An Automatic Analogue Computor for the Solution of Mine Ventilation Networks—D. R. Scott and R. F. Hudson. (*Jour. Sci. Inst.*, vol. 30, pp. 185–188; June 1953.)

681.142:519.272.119 3350
A Thermistor-Bridge Correlator—V. C. Anderson and P. Rudnick. (*Rev. Sci. Instr.*, vol. 24, pp. 360–361; May 1953.) The correlator described is designed to give a direct indication of the correlation coefficient between two cw signals. Two thermistors are used as mean-square elements in a circuit giving correlation coefficients to within about 1%.

681.142:538.221 3351
Digital Storage using Ferromagnetic Materials—A. E. De Barr. (*Elliott J.*, vol. 1, pp. 116–120; May 1953.) Four types of magnetic digit-storage system are described.

681.142:538.221 3352
An Analysis of Magnetic-Shift Register Operation—E. A. Sands. (PROC. I.R.E., vol. 41, pp. 993–999; Sept. 1953.)

681.142:621.385.832 3353
A Method for Improving the Read-Around Ratio in Cathode-Ray Storage Tubes—J. Kates. (PROC. I.R.E., vol. 41, pp. 1017–1023; Sept. 1953.)

MEASUREMENTS AND TEST GEAR

529.786 3354
Quartz Clocks of the Greenwich Time Service—H. M. Smith. (*Mon. Not. R. Astr. Soc.*, vol. 113, pp. 67–80; 1953.) A general account of the development and of the assessment of performance of the quartz clocks at Greenwich and Abinger is given. The criterion of performance, defined as the change in rate expressed in milliseconds per day per month per month, is of the order of 0.1 in modern ring-crystal-oscillator clocks, compared with a criterion value of 3.4 for the best pendulum clock of the Paris observatory. See also 2223 of 1951.

538.566:535.222 3355

Proposed Use of a Cylindrical Surface-Wave Resonator for the Determination of the Velocity of Short Electromagnetic Waves—H. M. Barlow and A. E. Karbowiak. (*Brit. Jour. Appl. Phys.*, vol. 4, pp. 186–187; June 1953.) The use of the cylindrical surface-wave resonator at a frequency between 1 and 40 kmc/s for the determination of *c* is suggested. The method of calculating the wave velocity is outlined, but no estimate of the ultimate accuracy of the method is made.

621.3.087.4:551.510.535 3356

Automatic Ionospheric-Height Recorder—C. Clarke and E. D. R. Shearman. (*Wireless Eng.*, vol. 30, pp. 211–222; Sept. 1953.) Description of "commercial equipment based on a design by Naismith and Bailey [1191 of 1951], for measuring the virtual heights of reflection of ionospheric echoes as a function of transmitted frequency. A pulse transmitter consisting of a master oscillator and power amplifier is tuned through the frequency range in five bands. The receiver is separately tuned and is kept in step with the transmitter by a frequency discriminator and servo-mechanism. The receiver output is presented on two cathode-ray tubes, one for monitoring and one for photographic recording, each displaying a linear time-base sweep. Height and frequency calibrations, which are derived from a crystal source, are displayed, and a crystal-controlled time switch is incorporated for the automatic operation of the equipment."

621.314.25 3357

A Phase Shifter for Use from 10–100 Mc/s—W. P. Melling. (*Elliott J.*, vol. 1, p. 115; May 1953.) Description of a goniometer type of phase shifter using crossed conductors in a metal cylinder closed by a rotatable cap carrying a pickup loop. See also 1735 of June (Thirup).

621.314.7:621.317.3 3358

Measurement of the Small-Signal Parameters of Transistors—G. Knight, Jr., R. A. Johnson and R. B. Holt. (PROC. I.R.E., vol. 41, pp. 983–989; Sept. 1953.) With input current and output voltage as independent variables, the set of parameters most appropriate for the description of circuit operation of junction transistors comprises (*a*) the short-circuit input conductance, (*b*) a specified voltage feedback ratio, (*c*) the short-circuit current gain, and (*d*) the open-circuit output resistance. Grounded-base connection only is considered. The measurement method applied in obtaining the dynamic impedance parameters [2863 of 1949 (Lehovec)] is also applied here. Circuit diagrams and a table giving measurement details for all parameters are presented. Sources of error and their elimination are discussed.

621.314.7:621.317.733 3359

Equipments for Measuring Junction-Transistor Admittance Parameters for a Wide Range of Frequencies—L. J. Giacoletto. (*RCA Rev.*, vol. 14, pp. 269–296; June 1953.) Description of the use of a commercially available bridge for the determination of conductance parameters associated with a junction transistor, at 1 kc, and also of the construction of four admittance bridges for the determination of transistor conductance and suceptance parameters as a function of frequency from 1 kc to 1 mc.

621.316.842/.843].025 (083.74) 3360

Alternating-Current Resistance Standards A. H. M. Arnold. (*Proc. IEE [London]*, part II, vol. 100, pp. 319–328; June 1953.) Basic design principles for resistance standards having a resistance within 0.01% of the nominal value and a phase angle $<10^{-4}$ radian at frequencies up to about 20 kc are described. Ni-Cr-Al alloys appear suitable for standards in which self-heating is considerable. Details are given of a 1-Ω standard comprising 21 bifilar units of Cu-Ni wire in parallel; the calculated phase angle is $<10^{-4}$ radian up to 30 kc. Formulas for eddy-current losses, inductance and capacitance of standards of various types are given.

621.317.333.4.015.7:621.315.2 3361

A Portable Pulse Test-Set for the Measurement of Impedance Irregularities in Coaxial Cables used for the Transmission of Television Signals—F. A. Vitha. (*Commun. News*, vol. 13, pp. 117–127; June 1953.) The theory of reflection at cable irregularities is reviewed. The equipment described comprises a transmitter unit and cro. Pulse duration can be either 0.05 or 0.25 μs. Pulse rate is controlled by an oscillator at one of nine frequencies between 10 and 300 kc or by triggering from an outside timing source. Cables of length from 50 m to 15 km can be tested. Accuracy is within ±3 m or ±5 m according to total cable length

621.317.7.029.6 3362

Instruments for use in the Microwave Band—A. F. Harvey. (*Proc. I.E.E.*, part II, vol. 100, p. 244; July 1953.) Discussion on paper abstracted in 1969 of 1952 (Harvey.)

621.317.715 3363

A Logarithmic-Scale Valve Galvanometer—G. Heiland and G. Rupprecht. (*Z. angew. Phys.*, vol. 5, pp. 167–171; May 1953.) Theory, design and applications of instruments with a working range of $10^{-12}-10^{-6}$ A.

621.317.723 3364

A Logarithmic-Scale Electrometer—W. Waidelich. (*Z. angew. Phys.*, vol. 5, pp. 171–173; May 1953.) The design of an es quadrant-type voltmeter for the range 10 V–1 kv is described.

621.317.733 3365

High-Resistance Bridge for Conductivity Measurements—M. Unz. (*Jour. Sci. Instr.*, vol. 30, pp. 179–184; June 1953.) The bridge described is suitable for measuring the conductivity of the ground or other specimens with unreliable contact surfaces.

621.317.733:[621.316.86:537.312.6 3366

Direct-Reading Thermistor Bridge—K. F. Treen. (*Electronic Eng.*, vol. 25, pp. 350–351; Aug. 1953.) Comment on 1749 of June (Pearson & Benson), and authors' reply.

621.317.733.011.21 3367

Wheatstone Bridge for Admittance Determinations—H. P. Schwan and K. Sittel. (*Elec. Eng.*, vol. 72, p. 483; June 1953.) Digest only. Description of a bridge for measurement (to within 0.1%) of resistances in the range 10Ω–100 kΩ and capacitances from zero to 1000 pf. The reactance calibration is independent of frequency for all resistors >100Ω.

621.317.74 3368

Design and Construction of an Accurate Standing-Wave-Ratio Meter for the 9.5-kMc/s Band.—J. Le Bot and S. Le Montagner. (*Jour. Phys. Radium*, vol. 14, pp. 299–303; May 1953.) A general discussion is given of the effects on wave propagation of the usual type of slotted guide and probe arrangement. Accuracy of machining and finishing the equipment described was such that the positions of the voltage minima were defined to within ±5μ.

621.317.755 3369

Automatic C.R.T. Trace Brightening for Varying-Amplitude R.F. Signals—J. de Klerk. (*Elec. Eng.*, vol. 25, pp. 388–389; Sept. 1953.) In photography of short trains of pulses of varying amplitudes, if the exposure is correct for the large-amplitude pulses, the small-amplitude pulses will be over-exposed. This difficulty is overcome by means of a circuit which automatically increases the brightness of the trace by an amount proportional to the signal amplitude. Typical oscillograms illustrate the use of the circuit.

621.317.755 3370

The Oscilloscope, Type GM 5660—T. M. W. van Velthoven. (*Commun. News*, vol. 13, pp. 139–146; June 1953.) Description, with circuit diagrams of the various units, of an instrument with a 10-cm screen and a special synchronization system for examination of transients of duration down to 0.1 μs.

621.317.755 3371

Some Special Oscillograph Techniques—F. M. Bruce. (*Jour. Brit. IRE*, vol. 13, pp. 303–314; June 1953.) Techniques and apparatus in use for investigation of transients in heavy-current equipment are described, including (*a*) a continuously evacuated oscillograph with the beam impinging directly on photographic film, (*b*) high-speed oscillographs for microsecond transients, (*c*) equipment for multiple recording with a high-speed drum camera, (*d*) a recurrent-surge cro for pulse tsets on transformers, (*e*) a recovery-voltage indicator for testing circuit-breakers.

621.317.755:512.99 3372

Study of a Vectorial Analyser—J. van Geen. (*HF, Brussels*, vol. 2, pp. 157–161; 1953.) Description of equipment for vectorial cro display of sinusoidal voltages. A circular-sweep timebase is used, the frequency being 1 kc. Applications to em wave propagation along an artificial transmission line and to sound-wave propagation in an echo-free room are illustrated.

621.317.755:621.397.6 3373

Testing of Television Studio Equipment by means of Synchronizing Pulses of Variable Phase—E. Demus. (*Fernmeldetech. Z.*, vol. 6, pp. 208–213; May 1953.) A "line selector" oscilloscope and its applications to 625-line equipment are described. Block diagrams and oscillograms illustrating various faults are given. Similar equipment was described by Fisher (1762 of 1952).

621.317.756+621.317.77 3374

A Harmonic-Response-Testing Equipment for Linear Systems—D. O. Burns and C W. Cooper. (*Proc. IEE [London]*, part II, vol. 100, pp. 213–221; June 1953. Discussion, pp. 221–222.) Detailed description of equipment for measurements in the frequency range 0.1–100 cps. Phase shift and attenuation are indicated on dials. The phase meter is an air-cored dynamometer with oil damping. With purely sinusoidal excitation of the fixed coil, the moving coil responds only to the fundamental component of the applied signal. Sinusoidal signals at the test frequency are obtained by demodulating a carrier-frequency signal which has been modulated electromechanically. The equipment includes a special amplifier for low-impedance coupling and a calibrated amplifier for attenuation measurements.

621.317.761.029.422 3375

Automatic Frequency Meter for Very Low Frequencies—F. Hubl. (*NachrTech.*, vol. 3, pp. 222–225; May 1953.) A description is given of the principles and design of a direct-reading meter suitable for measurement of the frequency difference between two standard-frequency sources. A system of sensitive relays is used to control the operating time of a motor coupled to a dc potentiometer, the current through which is a measure of the difference frequency.

621.317.794:621.362:537.311.33 3376

The Construction of Radiation Thermocouples using Semiconducting Thermoelectric Materials—D. A. H. Brown, R. P. Chasmar and P. B. Fellgett. (*Jour. Sci. Instr.*, vol. 30, pp. 195–199; June 1953.) An investigation is reported of methods of construction of thermocouples of the type described by E. Schwarz (British Patent Specifications Nos. 578187 and 578188). The composition of the thermoelectric materials is discussed. Performance figures for experimental thermocouples are given together with those obtained on commercial couples made by Schwarz.

621.396.615.17.018.75:621.397.62 3377
An Introduction to the Sine-Squared Pulse—G. J. Hunt and E. W. Elliot. (*Jour. Telev. Soc.*, vol. 7, pp. 49–59; April/June 1953. Discussion, p. 59.) The sine-squared, or "raised cosine," pulse is one in which each ordinate is the square of the corresponding ordinate of a half sine-wave. A description is given of a complete generator using in the squaring stage a rf pentode with signal applied simultaneously to control and suppressor grids; pulses of 0.34, 0.17, 0.1 and 0.05 μs are available. For testing the transient response of television or other low-pass systems, this type of pulse offers many advantages.

OTHER APPLICATIONS OF RADIO AND ELECTRONICS

620.179.1:677.72 3378
Electromagnetic Testing of Winding Ropes—A. Semmelink. (*Trans. S. Afr. Inst. Elec. Eng.*, vol. 44, pp. 113–129; May 1953.) Discussion, pp. 130–145.) Details are given of an ac test method in which a wire rope is magnetized longitudinally and flux variations are detected by means of a search coil.

621.316.71:666.16 3379
Electronic Control of Glass-Grinding Machines—(*Engineering*, [*London*], vol. 175. pp. 574–575; May 1, 1953.) Glass windows whose edges are to be ground are mounted on a rotating chuck whose rate of rotation is controlled by a cam-operated servomechanism to prevent excessive grinding speeds at critical points of the profile.

621.384.612 3380
Radiation by Electrons in Large Orbits—D. R. Corson. (*Phys. Rev.*, vol. 90, pp. 748–752; June 1, 1953.) Measured values of electron energy loss per orbit revolution in tne Cornell University synchrotron are in excellent agreement with values calculated from classical em theory.

621.384.613 3381
The Betatron—R. Wideröe. (*Z. angew. Phys.*, vol. 5, pp. 187–200; May 1953.) A clear account of the theory, development and applications of the betatron to date. 70 references.

621.385.833 3382
An Improved Scanning Electron Microscope for Opaque Specimens—D. McMullan. (*Proc. IEE* [*London*] part II, vol. 100, pp. 245–256; June 1953. Discussion, pp. 257–259.)

621.385.833 3383
Potential of an Electrostatic Electron Lens. Comparison of the Results of Calculations and of Measurements made in an Electrolyte Tank—M. Laudet and P. Pilod. (*Jour. Phys. Radium*, vol. 14, pp. 323–328; May 1953.)

621.385.833 3384
Space-Charge Requirements in Some Ideally Focused Electronoptical Systems—N. Wax. (*Jour. Appl. Phys.*, vol. 24, pp. 727–730; June 1953.)

621.385.833 3385
The Magnetic Circuit in Electron-Microscope Lenses—T. Mulvey. (*Proc. Phys. Soc.* [*London*], vol. 66, pp. 441–447; June 1, 1953.)

621.385.833 3386
The Effect of Pole-Piece Saturation in Magnetic Electron Lenses—G. Liebmann. (*Proc. Phys. Soc.* [*London*], vol. 66, pp. 448–458; June 1, 1953.)

621.385.833 3387
Focusing of High-Energy Particles by Grid Lenses: Part 1—The Convergence of Grid Lenses—M. Y. Bernard. (*Jour. Phys. Radium*, vol. 14, pp. 381–394; June 1953.)

621.385.833:537.12/.13 3388
Obtaining Electron Images of Surface Bombarded by Ions—A. Septier. (*Compt. Rend. Acad. Sci.* [*Paris*], vol. 237, pp. 231–233; July 25, 1953.)

621.387.424 3389
Application of Wilkinson's Theory to G-M Counters with External Cathode—D. Blanc and H. Zyngier. (*Compt. Rend. Acad. Sci.* [*Paris*], vol. 237, pp. 38–39; July 6, 1953.)

621.387.424 3390
Limitation of the Propagation of the Discharge in G-M Counters—E. Picard and A. Rogozinski. (*Jour. Phys. Radium*, vol. 14, pp. 304–306; May 1953.)

PROPAGATION OF WAVES

538.566 3391
A Note on Sommerfeld's 1909 Paper—B. M. Fannin. (Proc. I.R.E., vol. 41, pp. 1059–1960; Sept. 1953.) Comment on 2871 of 1950 (Kehan and Eckart)).

538.566 3392
Concerning Green's Reinterpretation of the Magnetoionic Theory—C. G. McCue. (*Jour. Atmos. Terr. Phys.*, vol. 3, pp. 239–244; June 1953.) In Green's equations of motion of an electron under the influence of the electric component of the radio wave, which were given in a handbook of the Ionospheric Prediction Service, NSW, Australia, October 1950, the x component of the electric wave vector is neglected. This invalidates the remainder of Green's analysis. Appleton's interpretation of the magneto-ionic theory appears to be sufficient at present. The calculation of the muf, when the magnetic field of the earth is taken into consideration, is discussed.

538.566 3393
Wave Propagation in an Anisotropic Inhomogeneous Medium—J. Feinstein. (*Jour. Geophys. Res.*, vol. 58, pp. 223–230; June 1953). The results are given of wave-theory calculations for the characteristic-mode polarizations and reflection coefficients for the case of finite gradients of electron density and an arbitrarily oriented geomagnetic field. Consideration of the variation of polarization with distance within the medium leads to a simple interpretation of the departures from geometrical optics. The treatment is extended to collision frequencies near the critical tube. Modifications introduced by the wave principles used are discussed and the results of lf polarization measurements are explained.

538.566:551.551 3394
Electromagnetic-Field Fluctuations due to Turbulence, at the End of a Line-of-Sight Propagation Path—J. Voge. (*Compt. Rend. Acad. Sci.* [*Paris*], vol 237, pp. 351–353; July 27, 1953.) Megaw (1105 of April) treated this problem on the basis of a turbulence spectrum physically the most probable. A Taylor type of spectrum is here assumed; this may be less correct, but is often simpler to use. Analysis for two cases considered, (*a*) ultra-short waves transmitted over a moderately great distance, (*b*) light waves, leads to formulas analogous to those of Megaw.

621.396.11:[550.385:523.72:621.396.822 3395
Relationship between Radio-Propagation Disturbance, Geomagnetic Activity and Solar Noise—van Sabben. (*See* 3283.)

621.396.11.029.6 3396
Large Reductions of V.H.F. Transmission Loss and Fading by the Presence of a Mountain Obstacle in Beyond-Line-of-Sight Paths—F. H. Dickson, J. J. Egli, J. W. Herbstreit and G. S. Wickizer. (Proc. I.R.E., vol. 41, pp. 967–969; Sept. 1953.) A graph of transmission-loss/obstacle-height for paths of 50 and 150 miles and frequency 100 mc is shown which is based on knife-edge diffraction theory. As compared with paths having no mountain obstacles paths with such obstacles will show considerable transmission gains provided particular combinations of antenna height, obstacle height and frequency are chosen. Experimental results for a 38-mc, 160-mile communication link in Alaska, with effective antenna height of 50 feet and obstacle height >8,000 feet, were in reasonable agreement with calculations. Field-strength records also showed absence of severe tropospheric fading.

621.396.11.029.62 3397
Study of Ultra-Short-Wave Propagation over the Barrier presented by the Alps—J. Dufour. (*Tech. Mitt. schweiz. Telegr.-Teleph-Verw.*, vol. 31, pp. 124–12–; May 1, 1953. In French.) The signal strengths of North Italian and South German FM transmitters operating in the 90–95 mc band were measured during the summer of 1952 at five stations in Switzerland. Recordings were made at three stations. The expected field-strength calculated from the free, space field, but allowing for diffraction at intervening ridges, agreed within 10 db with the measurement results which, apart from line-of-sight paths, show fair agreement with the CCIR curves. Rapid signal-strength variations were related to interference between the direct and the ground-reflected wave. Slow variations seemed to be due to refraction conditions. The absence of variations always corresponded to rainy windy weather. On two occasions the passage of a cold front coincided with marked signal increase. Apart from improved reception at high-altitude stations, the Alps are not found to introduce any new propagation effect.

RECEPTION

621.396.62+621.397.62:061.4 3398
Radio and Television at the Paris Fair—P. A. François. (*TSF et TV*, vol. 29, pp. 202–206 and 241–242; June/Aug. 1953.) 133 radio receivers exhibited, including one FM receiver, are classified, with indications of ranges, number of tubes, etc. Trends in design are noted.

621.396.621 3399
The Reception of Frequency-Shift Signals from Short-Wave Transmitters—H. Bohnenstengel. (*Fernmeldetech. Z.*, vol. 6, pp. 249–253; June 1953.) The effect of interference on the reception of frequency-shift signals is analyzed. A table is given relating bandwidth, mean effective noise voltage, the minimum voltage required for reception for (*a*) recorder operation with amplitude keying, (*b*) frequency-shift keying, (*c*) printer operation, and the permissible frequency shift using a minimum keying-pulse time of 20 ms. The effect of fading on reception is also investigated. The efficacy of normal frequency-shift systems is attributed to amplitude limitation. A frequency-diversity system using two values of frequency shift, or additional FM of the frequency radiated, is recommended.

621.396.621 3400
Magnetic Demodulation—L. Pungs and G. Meinshausen. (*Frequenz*, vol. 7, pp. 153–160; June 1953.) The magnetic-flux/field-strength characteristic is made use of for demodulation which results from the rectification of the induction flux. Demodulation of A and B types, depending on the point of op-

eration on the Φ/H curve, is discussed by analogy with demodulation by means of nonlinear resistors. The circuit and method used in the determination of the rectification characteristic curves are described and examples of load-line determination of the dynamic characteristics are given.

621.396.621:621.396.822 3401

Signal-to-Noise Ratios, in Band-Pass Limiters—W. B. Davenport, Jr. (*Jour. Appl. Phys.*, vol. 24, pp. 720–727; June 1953.) A general analysis is made of the relation between the output signal and noise powers and the input signal and noise powers for band-pass limiters whose transfer characteristic is a nondecreasing odd function of its argument. Specific results are given for the case where the limiter output is proportional to the *n*th root of its input; they include the ideal symmetrical limiter as a limiting case. The output signal/noise power ratio is essentially directly proportional to the input signal/noise power ratio for all values of the latter. This is due to the band-pass characteristics, rather than to the symmetrical limiting action.

621.396.621:621.396.822.523.72 3402

Radio-Noise Receivers—J. L. Steinberg. (*Onde élect.*, vol. 32, pp. 445–454 and 519–526; Nov./Dec. 1952. vol. 33, pp. 274–284, June 1953.) A detailed account of work carried out from 1947 to 1950. The conditions were determined which receiving equipment must satisfy if it is to be used for measurement of uhf radiation. The known characteristics of solar rf radiation are reviewed and the operation of a receiver is analyzed for the case when the level of the received rf noise is small compared with the tube and circuit noise of the receiver itself. With regard to the measurement of temperatures, noise factor is defined, and statistical analysis is presented of the fluctuations in the measurement apparatus at the output of the receiver after the detector. A method of eliminating fluctuations of gain by use of a permutation system at the input of the receiver is described. This system of modulation results in an increase of the ratio of useful signal to noise and hence of the stability in all cases, even when gain fluctuations are absent. Various modulation systems are critically discussed and a new system is described. The relation between noise factor N/and bandwidth Δf is considered. A minimum value of the quantity $N\sqrt{\Delta f}$ is required; this condition introduces circuit problems different from those met with in normal radiocommunication practice. Measurements of the spectrum of gain fluctuations, made with a selective amplifier and a noise generator modulated with square waves, show that the spectrum extends much farther towards high frequencies than is indicated by American investigators. A complete description is given of rf noise-measurement equipment operating on 1.2 kmc with a noise factor of 11 db and an input bandwidth of 10 mc. With this equipment a variation of apparent antenna temperature of ±1°K can be detected. With the antenna actually used, a received power of 4×10^{-23} W/cm² can be detected. Apparatus operating with a larger aerial in 158 mc, but with a smaller bandwidth, can detect a power of $2.5\times10{:}^{23}$ W/cm². Results of observations made with this equipment during the eclipse of the sun on 28th April 1949 are described and discussed in relation to optical measurements.

621.396.621.54:621.314.7 3403

Transistorized Superhet Receiver—(*Electronics*, vol. 26, pp. 202, 205; Aug. 1953.) Description abstracted from a paper entitled "Application of Transistors to Radio-Receiver Circuitry," by E. Toth. The special problems arising in receiver design owing to transistor characteristics such as low input impedance, high output impedance, low power-handling capacity, etc., are discussed. The receiver described has one rf amplifier stage (550 kc–1.55 mc), mixer, heterodyne oscillator operating 455 kc above the signal frequency, three 455 kc IF amplifier stages, crystal-diode second detector, af pre-amplifier and af output stage, 8 transistors being used. Gain control is effected by ganged potentiometers at the inputs of the rf amplifier and the first IF amplifier. An input of about 200 μV is required for 6 mw output at 1 kc, with 10 db output signal/noise ratio. Maximum power output is about 15–20 mw for 5% harmonic distortion at 1 kc. The total dc power required is about 1 w:3 v, 8 ma for the emitter bias circuits, and 30v, 30 ma for the collector circuits.

621.396.622:621.396.822 3404

Decrease of the Low-Frequency Signal-to-Noise Ratio when Increasing the Intermediate-Frequency Bandwidth, using a Square-Law or a Linear A.M. Detector—H. de Lange Dzn. (*Commun. News*, vol. 13, pp. 128–138; June 1953.) Mechanical analogy suggests that for calculations relating to linear detection, a lf noise voltage can be treated as an AM and phm carrier having the same frequency as that of the system. This provides a simpler method of calculation than that of Fränz (3026 of 1941, and 443 of 1944). Taking particular account of the relation between lf and IF noise spectra, Burgess's analysis for a linear detector (3098 of 1951) is modified to give results in closer agreement with experiment. Calculations of the relation between bandwidth and signal/noise ratio for different levels of modulation show that IF bandwidth can be increased considerably with only a moderate reduction of signal/noise ratio, particularly with linear detection. The use of preamplification to ensure linear operation of a detector is justified even for threshold signals.

621.396.622:621.396.822 3405

The Output Signal-to-Noise Ratio of a Power-Law Device—N. M. Blachman. (*Jour. Appl. Phys.*, vol. 24, pp. 783–785; June 1953.) First-order statistics are applied to the problem of a power-law device fed by a sinusoidal signal and narrow-band random noise, to obtain an expression for the signal/noise power ratio for the output components in the vicinity of any harmonic of the input signal, in terms of the input signal/noise power ratio. Formulas are given for the cases of large and small values of the input ratio. See also 2168 and 2169 of 1945 (Rice), and 1175 of 1949 (Middleton).

621.396.822:621.317.34 3406

The Measurement and Assessment of Background Noise—E. Belger. (*Tech. Hausmitt. NordwDtsch. Rdfunks*, vol. 5, pp. 51–59; March/April 1953.) The characteristics of noise meters are surveyed and experimental results of subjective tests made to determine the permissible signal/noise ratio are given. The average ratio to be aimed at is ~55 db, but 45 db is tolerable for most types of modulation and even at 35 db the quality of many programs is satisfactory.

STATIONS AND COMMUNICATION SYSTEMS

016:621.396.931 3407

Metre Waves in Mobile Services—R. Hermann. (*Onde élect.*, vol. 33, pp. 347–352; May 1953.) Classified bibliography of papers and books published in U.S.A., Europe and Australia before February 1952, dealing with mobile communication systems and equipment.

621.394.333:621.018.78 3408

Oscillographic Representation of the Degree of Distortion in Teletype Signals—K. W. Seiffert. (*Fernmeldetech. Z.*, vol. 6, pp. 214–217; May 1953.) The degree of general distortion and the degree of relative distortion are defined and two cr instruments used to measure them are described.

621.395.44 3409

The L3 Coaxial System: System Design—C. H. Elmendorf, R. D. Ehrbar, R. H. Klie and A. J. Grossman. (*Bell Sys. Tech. Jour.*, vol. 32, pp. 781–832; July 1953.) Design problems and requirements for the system, which provides 1860 telephony channels or 600 telephony channels and a television channel in each direction on a pair of coaxial cables, are discussed and methods adopted to meet the requirements are described. An account is given of the main features of the terminal and repeater equipment.

621.395.44:[621.395.521.3+621.395.664 3410

The L3 Coaxial System: Equalization and Regulation—R. W. Ketchledge and T. R. Finch. (*Bell Sys. Tech. Jour.*, vol. 32, pp. 833–878; July 1953.) A theory of the equalization of complex systems is outlined and the location and function of the various equalizers are explained. The analogue computer used in the regulation system is described and also the cosine-equalizer adjustment technique used with manual equalizers. Details of the circuits and operation of the regulation system are given.

621.395.44:621.395.645 3411

The L3 Coaxial System: Amplifiers—L. H. Morris, G. H. Lovell and F. R. Dickinson. (*Bell Sys. Tech. Jour.*, vol. 32, pp. 879–914; July 1953.) The circuits and mechanical design of the line amplifiers and the flat-gain amplifiers are described. The two types are basically similar, consisting of two feedback amplifiers in tandem coupled by a network which, in the case of the line amplifier, is variable and is automatically adjusted to compensate for variations in cable temperature and for small deviations from the nominal 4-mile spacing of repeaters. All important components are subject to strict quality control to ensure uniformity of amplifier performance.

621.396.4:621.396.65 3412

Experimental Radio Bearer Equipment for Carrier Telephone Systems—W. S. McGuire and A. G. Bird. (PROC. I.R.E., vol. 14, pp. 135–147; Sept./July 1953.) Two FM bearer systems are described, for the frequency ranges 420–470 mc and 860–960 mc respectively. Both are crystal controlled, with a frequency deviation of ±180 kc and a carrying capacity of 12–17 telephone channels. The performance of both systems meets CCIF requirements when used with the appropriate carrier equipment. Intermediate relay stations re-radiate on a frequency slightly different from that of the received signal. Details are given of a typical installation comprising transmitter, repeater and receiver for the 420–470 mc band, and its performance over a 100-mile circuit is reported.

621.396.619.13:621.392 3413

A.M.-F.M. Analogy—Harris (*See* 3246.)

621.396.619.16 3414

Coding by Feedback Methods—B. D. Smith. PROC. I.R.E., vol. 41, pp. 1053–1058; Sept. 1953.) The feedback coder converts an analogue quantity, such as a voltage, into a digital quantity. It comprises an error amplifier, control circuits and a decoding network which is used as the feedback element in the amplifier. The binary coder is considered in detail, and the principles of binary-coded decimal systems are briefly mentioned. The feedback coding method is compared with the counting and coding-tube methods, and a system of nonlinear coding is outlined.

621.396.619.16 3415

New Method of Modulation with Reduced Bandwidth—F. Benz. (*Öst. Z. Telegr. Teleph.*

Funk Fernsehtech., vol. 7, pp. 66–75; May/June 1953.) Two equal carriers 90° out of phase are modulated by the outputs of two tubes in push-pull. These tubes are driven by an alternating pulsed input, the modulation voltage being applied to the screen grids in parallel. The two modulated carriers are combined and amplified. For the same hf bandwidth, the received lf bandwidth is twice that obtaining in other modulation systems. For reception, two IF signals are derived and demodulated separately before being applied to a phase-discriminator combining circuit. Reception is possible using a normal AM receiver. Distortion due to inaccurate phase and frequency transformations in the receiver is calculated and the application of the method in pwm, pphm and pcm systems is discussed.

621.396.722 3416
International Monitoring—J. T. Dickinson. (*Wireless World*, vol. 59, pp. 422–423; Sept. 1953.) Functions and equipment of the receiving station of the European Broadcasting Union, opened in July 1953 at Jurbise-Masnuy, near Mons, are briefly described. Continuous watch is kept, covering all broadcasting bands. Two frequency standards are housed in an underground compartment, one of modified Telefunken design with outputs of 1, 10, 100 and 1000 kc derived from a 500-kc quartz crystal, the other of American manufacture. Fequency monitoring, accurate to within 4 or 5 parts in 10^7, is based on heterodyning the received signal with an appropriate rf signal of known frequency injected into the receiver. For lf and mf reception, inverted-L antennas are used; for hf, elevated horizontal dipoles; for vhf, a rigid horizontal dipole. Large rotating frame antennas facilitate reception in crowded channels.

621.396.931 3417
Problems Concerning Radio Transmission for Telephone Links with Mobile Stations—W. Klein. (*Tech. Mitt. schweiz. Telegr.-Teleph-Verw.*, vol. 31, pp. 145–168; vol. 31.) French version of paper abstracted in 1486 of May.

621.396.932 3418
Radiotelegraphy, Radiotelephony and Navigational Aids Aboard Merchant Ships and Fishing Vessels—L. Lahure and J. Fontaine. (*Onde élect.*, vol. 33, pp. 289–299; May 1953.) A review of the development of ships' radio apparatus from the first transmitters to modern equipment based on recommendations of recent conventions.

621.396.933 3419
Telecommunications and Radio Aids in Civil Aviation—(*Onde élect.*, vol. 33, pp. 249–288; May 1953.) Seven papers reviewing postwar developments:

Organization of Civil Aviation—Portier. An outline of national and international arrangements.

Telecommunications in Civil Aviation—G. Hoerter. An account of traffic and navigation systems required for different air services.

Control Towers—Macelloni & Vannel. Description of equipment lay-out and vhf R/T recording and df apparatus.

Central Telecommunications Office—Quiquandon and Lalmi. Operation of telegraph and telephony services and receiving equipment of a typical center are described.

H.F. Transmitters for Aerodromes—Nill. Illustrated general description of a standard series of fixed-frequency transmitters for 50 w, 300 w, 1 kw and 10 kw.

Radio Aids to Air Navigation—Villiers. A review of past and present systems, in particular loran and consol, vor/dme, and Decca, and instrument landing systems H_s, and gca.

Radio Installations at French Overseas Aerodromes—Bargain. A note on the phases of development, with a map showing the services planned for different airfields, particularly in N.W. Africa.

SUBSIDIARY APPARATUS

621-526 3420
A Study of a Second-Order Sampling Servo—S. R. Cooper. (*Elec. Eng.*, vol. 25, pp. 342–349; Aug. 1953.)

621-526 3421
Operating Modes of a Servomechanism with Nonlinear Friction—H. Lauer. (*Jour. Frank. Inst.*, vol. 255, pp. 497–511; June 1953.)

621-526 3422
Considerations on Discriminators in Airborne Servo Systems—J. C. Gille. (*Onde élect.*, vol. 33, pp. 337–342; May 1953.) Discussion of performance requirements for automatic-pilot mechanisms.

621-526 3423
Reduction of Forced Error in Closed-Loop Systems—L. H. King. (PROC. I.R.E., vol. 41, pp. 1037–1042; Sept. 1953.)

TELEVISION AND PHOTOTELEGRAPHY

621.397.242:621.395.44 3424
The L3 Coaxial System: Television Terminals—J. W. Rieke and R. S. Graham. (*Bell Sys. Tech. Jour.*, vol. 52, pp. 915–942; July 1953.) The special requirements of terminal equipment for the transmission and reception of television signals are discussed. The transmitting and receiving equipments are described, with details of the modulation process, vestigial-sideband operation, filter characteristics, pilot-frequency generator, etc.

21.397.26:621.396.65 3425
The Hinsbeck Relay Station in the International Television Link on the Occasion of the Coronation—H. Ehlers and G. Droscher. (*Tech. Hausmitt. NordwDtsch. Rdfunks*, vol. 5, pp. 33–36; March/April 1953.) The planning of the station is discussed and the equipment used in the relay described, with a block diagram showing the arrangements for duplicate reception and retransmission to Wuppertal for distribution to the NWDR network.

621.397.26:621.396.65 3426
New Television Directional Radio Links of the Federal German Post Office—(*Fernmeldetech. Z.*, vol. 6, pp. 220–233 and 269–279; May/June 1953.) A series of seven articles by various authors giving a description of the complete system linking Hamburg and Cologne, with the recent extension to Frankfurt am Main. See also 1431 and 2033 of 1952 (Schmidt), and 2160 of July (Behling et al.).

621.397.335:535.623 3427
A Subjective Study of Color Synchronization Performance—M. I. Burgett, Jr. (PROC. I.R.E., vol. 41, pp. 979–983; Sept. 1953.) The circuits associated with five main color receiver functions are so grouped that noise can be introduced into each separately in amounts controllable by the observer, who varies the noise to match each of 7 standard comments ranging from "not perceptible" to "not usable." NTSC signals are applied, and a monochrome receiver is also used for comparison. Results obtained by 10 observers indicate that noise in the color-synchronization circuit has relatively little adverse effect on picture quality, compared with noise in the luminosity-information or deflection-synchronization circuits.

621.397.5:535.623 3428
Principles and Development of Color-Television Systems—G. H. Brown and D. G. C. Luck. (*RCA Rev.*, vol. 14, pp. 144–204; June 1953.) A review of the development of compatible color-television systems by the RCA from 1940 to 1953 is given and the fundamentals of colorimetry and the physiology of vision are discussed. The 1953 NTSC field-test specifications are given in an appendix.

621.397.5:535.623 3429
Colorimetric Analysis of R.C.A. Color-Television System—D. W. Epstein. (*RCA Rev.*, vol. 14, pp. 227–258; June 1953.) An outline of the principles of colorimetry is given, and the effects of camera spectral characteristics and studio lighting on the fidelity of reproduction in the RCA compatible color-television system are analyzed.

621.397.6:621.317.755 3430
Testing of Television Studio Equipment by Means of Synchronizing Pulses of Variable Phase—Demus. (*See* 3373.)

621.397.61:535.623 3431
Optimum Utilization of the Radio-Frequency Channel for Color Television—R. D. Kell and A. C. Schroeder. (*RCA Rev.*, vol. 14, pp. 133–143; June 1953.) Discussion of the technical and physiological considerations on which the NTSC specifications of the field-test signal are based.

621.397.611.2 3432
Standards Converter for International TV—A. V. Lord. (*Electronics*, vol. 26, pp. 144–147; Aug. 1953.) Description of the principles and construction of equipment of the type used for conversion of programs from the French 819-line standard to the British 405-line standard. See also 2469 of August.

621.397.611.2 3433
Signal Generation in Television Camera Tubes: Part 2—Construction, Operation and Performance of the Different Types of Tube—R. Theile. (*Arch. elekt. Übertragung*, vol. 7, pp. 281–290, and pp. 328–337; June/July 1953.) See 1828 of June. Part 1, 1829 of June.

621.397.62 3434
A 427/45-Mc/s Converter for the Society's Television Transmissions—D. N. Corfield. (*Jour. Telev. Soc.*, vol. 7, p. 86; April/June 1953.) Corrections to paper abstracted in 2809 of September.

621.397.62+621.396.62]:061.4 3435
Radio and Television at the Paris Fair—François. (*See* 3398.)

621.397.62:535.623 3436
Color-Television-Signal Receiver Demodulators—D. H. Pritchard and R. N. Rhodes. (*RCA Rev.*, vol. 14, pp. 205–226; June 1953.) The basic concepts of a simultaneous subcarrier color system are described, with particular reference to the receiver demodulator problem. The design of demodulators for the NTSC type of signal is discussed and examples are given of practical circuits.

621.397.62:621.396.615.17.018.75 3437
An Introduction to the Sine-Squared Pulse—Hunt and Elliott. (*See* 3377.)

621.397.62:621.396.662 3438
Factors Affecting the Design of V.H.F.-U.H.F. Tuners—E. H. Boden. (*Sylvania Technologist*, vol. 6, pp. 64–67; July 1953.) Design requirements for the stages of a single tuner for U.S. channels 2–83, utilizing Type-6AN4 triodes in the rf amplifier and mixer stages and a Type-6T4 triode as oscillator tube, are considered. Three possible tuner circuits are examined. Noise-figure and gain measurements made on the compromise tuner gave values of 7–14 db and 25–20 db respectively, in the frequency range from channel 2 to channel 83.

621.397.621 3439
In Search of the Perfect Raster—P. J. Edwards. (*Jour. Telev. Soc.*, vol. 7, pp. 60–76;

April/June 1953.) Defects considered are: (*a*) inaccurate interlace; (*b*) deformities of the complete raster and of the individual scanning lines; (C) nonlinearity of scan; (*d*) nonuniformity of focus. The adverse influence of incorrect synchronization is considered and a description is given of a synchronization separator circuit using a cathode-coupled limiter. Good raster shape and linear scanning fields can be obtained by using deflection coils with suitably graded windings.

621.397.621.2:535.623 3440
The Preparation of Phosphor Screens for Color-Television Tubes—S. Levy and A. K. Levine. (*Sylvania Technologist*, vol. 6, pp. 60–63; July 1953.) A photographic method for the preparation of three-dot screens for color-television tubes is described. A paste consisting of a green, red or blue phosphor mixed with a photosensitive binder is applied to the glass screen and is illuminated by a point source of light through a mask of the desired pattern. The screen is then developed, fixed and the unexposed areas are washed away by a solvent. The process is repeated for the other colors. A permanent silicate binder is sprayed on, after removing the photosensitive binder by baking at 400°C.

621.397.826 3441
Influence of Echoes on Television Transmission—P. Mertz. (*Jour. Soc. Mot. Pict. Telev. Eng.*, vol. 60, pp. 572–596; May 1953.) Image distortion due to echoes is classified in terms of the characteristics of the echo signals, and tolerances for small- and large-screen television pictures in respect of over-all phase drift, envelope delay and phase delay are estimated.

TRANSMISSION

621.396.619.14 3442
Susceptance Valves and Reactance Valves as Phase Modulators—A. van Weel. (*Jour. Brit. IRE*, vol. 13, pp. 315–320; June 1953.) In two of the three basic ways of connecting a triode to operate as a variable impedance, the grid-anode capacitance is effectively in parallel with the circuit impedance. The application of these "susceptance" tubes for phm is described, only one tube being necessary to introduce phase variations up to 45° with mutual-conductance variations $\not<$0.5 ma per volt. A pentode grounded-anode susceptance-tube circuit and a pentode reactance-tube circuit, both providing a phm output current, are described.

621.396.932 3443
Some Problems in the Design of Marine Transmitters—D. J. Spooner. (*Jour. Brit. IRE*, vol. 13, pp. 325–330; June 1953.) Technical requirements in transmitter design in respect of frequency stability, bandwidth, power output and keying, based on official performance specifications, are discussed. Recommended "type-approval" tests, including a sequence of climatic and durability tests, are described.

TUBES AND THERMIONICS

537.311.33:621.314.7 3444
Transistors: Theory and Application: Part 6—Operation of Junction Transistors—A Coblenz and H. L. Owens. (*Electronics*, vol. 26, pp. 156–161; Aug. 1953.) Discussion of the physical and electrical properties of transistor triodes and tetrodes, *p-n-p-n* junctions, and the phototransistor. Part 5, 3021 of October.

621.314.7 3445
Unipolar 'Field-Effect' Transistor—G. C. Dacey and I. M. Ross. (PROC. I.R.E., vol. 41, pp. 970–979; Sept. 1953.) The field-effect transistor is essentially a structure containing a semiconducting current path, the conductivity of which is modulated by the application of a transverse electric field. Modifications are made to Shockley's ideal theory to take account of the following factors: (*a*) series resistance at the source and/or drain contacts, (*b*) carrier depletion, (*c*) negative gate resistance, (*d*) temperature effects. Design charts are then developed and their use explained. Details of results obtained with experimental units differing slightly in their dimensions are given. The results are in substantial agreement with the modified theory. Units having stable characteristics, transconductances up to 0.3 ma per volt and flat frequency response to 3 mc have been produced.

621.314.7:537.311.33:546.289 3446
Mechanism of Point-Contact Transistors—Thedieck. (*See* 3331.)

621.383.032.2 3447
Development of the Ca-AgO Photocathode During Thermal Treatment—V. Schwetzoff. (*Compt. Rend. Acad. Sci.* [*Paris*], vol. 237, pp. 320–322; July 27, 1953.) The observed changes of photoelectric and secondary emission are shown graphically and discussed.

621.383.2.014.33 3448
Pulse Irradiation of Composite Photocathodes with Intermediate Semiconducting Layers—W. Kluge and S. Weber. (*Naturwissenschaften*, vol. 40, p. 315; June 1953.) Pulse illumination of Ag-Cs_2O-Cs cathodes in vacuum photocells resulted in no fatigue. The illumination with white light was varied up to 10^7 Lux, with a pulse width at half maximum intensity of 15 μs. The saturation pulse current was proportional to the intensity of illumination.

621.383.42 3449
The Modern Single Layer Selenium Photoelectric Cell—G. A. Veszi. (*Jour. Brit. IRE*, vol. 13, pp. 183–189; April 1953.) Review of photocell development and applications.

621.385:537.525.92 3450
Propagation of Space-Charge Waves in Infinite and Finite Electron Beams—P. Parzen. (*Elec. Commun.*, vol. 30, pp. 134–138; June 1953.) Small-signal theory is developed for the case of beams of infinite lateral extent in planar diodes. The theory yields results in agreement with those of Llewellyn and Peterson (2578 of 1944) but can more readily be extended to deal with finite beams and with the effects of thermal velocities. Its application is not restricted to diodes. The analysis is relevant to the properties of traveling-wave tubes.

621.385.017.72 3451
The Vapotron—G. Ashdown. (*Elec. Eng.*, vol. 25, pp. 378–379; Sept. 1953.) A detailed account of the vaporization method of cooling high-power transmitting tubes has previously been given by Buertheret (542 of 1952).

621.385.029.6 3452
Effect of Thermal-Velocity Spread on the Noise Figure in Traveling-Wave Tubes—P. Parzen. (*Elec. Commun.*, vol. 30, pp. 139–154; June 1953.) Reprint. See 2934 of 1952.

621.385.029.63/.64 3453
On the Theory of the Helix-Type Traveling-Wave Valve—E. I. Vasil'ev and V. M. Lopukhin. (*Zh. tekh. Fiz.*, vol. 22, pp. 1838–1842; Nov. 1952.) A theoretical investigation of the effect of the velocity scatter of the beam electrons on the range of the existence and on the value of the complex roots of the dispersion equation for a traveling-wave tube using a helix.

621.385.029.64 3454
Traveling-Wave Oscillator Tunes Electronically—H. R. Johnson and J. R. Whinnery. (*Electronics*, vol. 26, pp. 177–179; Aug. 1953.) Details are given of the construction and operating characteristics of an electrically short tube with an output >100 mw at 3 kmc. By variation of the helix voltage, a 4.5% change of frequency is obtainable. The electrical length is 14 λ. External feedback through a filter eliminates undesired oscillation modes.

621.385.032.216:537.581:537.311.32 3455
Relationship between Thermionic Emission and Electrical Conductivity of Oxide-Coated Cathodes—S. Narita. (*Jour. Phys. Soc.* [*Japan*], vol. 8, pp. 331–338; May/June 1953.) (Ba, Sr)CO_3 and sintered $BaCO_3$ cathodes are investigated. A new emission and conduction mechanism is proposed for oxide-coated cathodes.

621.385.832/621.396.662 3456
A New Type of Tuning Indicator for Battery or Mains Receivers—H. P. White. (*Mullard tech. Commun.*, vol. 1, pp. 104–110; July 1953.) Full details are given of the new Mullard DM70 tuning indicator. It has a simple electrode structure and a 1.4v filament.

621.387 3457
The Characteristics of some Large-Current Glow-Discharge Tubes—F. A. Benson. (*Elec. Eng.*, vol. 25, p. 321; Aug. 1953.) Short-time characteristics of Type-CV1199 tubes, designed for the current range of 30–180 ma, are reported.

621.396.615.141.2 3458
Theory of the Multisegment Magnetron—V. I. Kalinin and T. P. Ryazonova. (*Zh. tekh. Fiz.*, vol. 22, pp. 1592–1598; Oct. 1952.) The results obtained by Slutskin (1839 of 1948) are further developed to cover the case when the modulation of the density of the tangential electron stream is taken into account. The discussion is based on the consideration of an electrical circuit equivalent to a multisegment magnetron (Fig. 1) and a general formula (12) is derived for the mean energy exchange between the electron streams and the slots during one cycle. Several particular cases are considered in detail; the theoretical conclusions are in good agreement with experimental results.

621.396.615.142 3459
Debunching of Electron Beams constrained by Strong Magnetic Fields—N. Chodorow, E. L. Ginzton and E. J. Nalos. (PROC. I.R.E., vol. 41, pp. 999–1003; Sept. 1953.) Feenberg's solution of the equations of electron motion in vm tubes is arbitrarily extrapolated to cover large values of the bunching parameter. Experiments to test the validity of this procedure were made on a conventional type of two-cavity klystron. With increasing value of the debunching parameter, the ouput rf current decreased and the input voltage required to produce maximum output current increased. Voltages at the cavity gaps were well below the beam voltage in all experiments. A phase reversal of output current at a particular value of beam radius was observed. Experimental results are in reasonable accordance with theory, when this is corrected for nonuniformity of the beam crosssection. The extrapolation may be considered valid for values of the debunching parameter <3.5 and of the bunching parameter <4.

MISCELLANEOUS

001.891:621.396 3460
Radio Research 1952 [Book Review]—Publishers: H.M. Stationery Office, London, 1953, 51 pp., 2s—(*Elec. Jour.*, vol. 151, p. 262; July 24, 1953.) Reports of the work carried out during 1952 at the Radio Research Station, Slough, at overseas stations, and at British universities collaborating with DSIR.

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I.R.E. STANDARDS

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