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IEEE spectrum

features

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THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

departments

the cover

A montage of U.S. railroad logotypes "tells" an abstract picture story of the expansion of ground transportation from coast to coast. For the historical background—and future—of railway electrification, see the article that starts on page 50.

Spectral lines

Continuing education. A few generations ago, English literary and biographical writing abounded in the man who typically "went to Westminster School, spent two years at Oxford, and completed his education by touring for a year on the Continent." Even in those less remote times when the most exciting thing in electrical engineering courses was the field rheostat, many a young engineer doubtless felt on graduation day that his education had been completed. However, he was in for a surprise. Twenty years later, he needed to know about vacuum tubes or servo systems or waveguides or Boolean algebra, and he had either continued his education or switched to selling insurance.

Education has been that process by which a group formulates and transmits its traditions. Its unspoken purpose has been to ensure that a culture shall outlast the human lifetime. Actually, "unspoken" does not cover all cases. Higher education in the United States was started by men who said clearly what it was for:

> "After God had carried us safe to New England, and wee had builded our houses . . . one of the next things we longed for and looked after was to advance Learning and perpetuate it to Posterity; dreading to leave an illiterate Ministry . . . when our present Ministry shall lie in the Dust. And as wee were thinking and consulting how to effect this great Work; it pleased God to stir up the heart of one Mr. Harvard . . ."

As the values of the nations became secularized, so did the values of the universities, but their goal was still to deepen the graduate's understanding of the culture into which he was born, or thrown. It was expected that the culture would change but little in his time. That assumption is now obsolete. Technology is the basis of our culture, and old men today have probably seen in their one lifetime more technological change than had occurred in the two thousand years that separated their parents from Julius Caesar.

When profound cultural change occurs in less than one lifetime, the goals of education have to be reconsidered, and the process itself must undergo change. The present upheaval in France exists in part—and perhaps in major part—because the academic process there has not evolved fast enough; it is (or was, before it broke down) trying to preserve a culture that no longer exists. In the United States there is unrest because the culture that the universities are engaged in transmitting is only a subculture—the culture of the university. Within memory, the ideal toward which undergraduate education in America strove was The Educated Man (male or female), who would take a place in society and help to guide it, with understanding, toward desirable ends. Now the goal is The Well-Prepared Graduate Student. This change has been more marked and more harmful in the humanities, including science, than it has been in engineering.

What innovations are needed in the education of engineers? Since the activity of engineering is going to change importantly during a working lifetime, the educational machine cannot do its work all in one pass, unless in that single operation it prepares a man to train himself in new skills as the need for them arises. If he is brought to the doctoral level, he should be able to keep up his education by his own efforts, but most graduates will want organized instruction.

In the present period of transition, we must improvise. A device that is proving useful is the short course offered at a university, or elsewhere. Its popularity indicates that this kind of undertaking is responding to a need. One of the features of the present issue of IEEE SPECTRUM is a catalogue of the short courses that are to be offered in the United States during the coming months.

Ultimately, a whole new system is demanded. Two elements seem especially important. One is the undergraduate training that is to prepare a man for his continuing education. The other is the facilities and procedures for the post-graduate learning. It is not apparent, and probably is not true, that the present habitudes of university training yield the best possible preparation for decades of subsequent study.

The pattern of post-graduate learning has to evolve first. Many schemes of going back to the university, or even of having the university come to the engineer, rise readily to mind. So do many obstacles. It seems likely that here is a new and vital role for the professional societies. Continuing education has always been their reason for being. Traditionally they have served their members through meetings and journals that publicize new work. Seldom have they had systematic programs of instruction, but now that such a service is needed by men who have full-time employment, professional societies seem to be the natural agents for providing it, because they unite the people who need it, and also they provide a locus for interaction between academic and industrial experts. Coordination with the universities should not be any harder to achieve than the coordination among universities that would be called for if they were to take on the whole responsibility.

J. J. G. McCue

Authors

Men, machines, and languages (page 44)

John R. Pierce (F) joined the Bell Telephone Laboratories in 1936 after receiving the Ph.D. degree from California Institute of Technology. He now is executive director, research, of BTL's Communications Sciences Division, with responsibilities in such fields of research as radio, electronics, acoustics and vision, mathematics, and psychology. Dr. Pierce is the author of nine technical books, many technical articles, and several published science fiction stories. He is the recipient of the 1942 Eta Kappa Nu Award, 1947 Morris Liebmann Memorial Prize, 1960 Stuart Ballantine Medal, 1962 Air Force Association H. H. Arnold Trophy, 1962 Golden Plate Award of the Academy of Achievement, 1963 Arnold Air Society General Hoyt S. Vandenberg Trophy, 1963 Edison Medal, 1963 Valdemar Poulsen Medal, 1963 National Medal of Science, 1964 H. T. Cedergren Medal, and 1966 Caltech Alumni Distinguished Service Award. He also has received six honorary doctoral degrees. He is a Fellow of the American Academy of Arts and Sciences, the American Physical Society, and the Acoustical Society of America.

The modern engineering bandwagon (page 79)

A. D. Moore (F, L) began his "retirement furlough" from the University of Michigan in 1964 after serving continuously on the faculty of the Electrical Engineering Department for 47 years. For Prof. Moore, his retirement has meant the chance to travel across the United States, giving lectures and demonstrations on electrostatics and fluid mappers. He is widely known in the electrical engineering field for his many inventions and innovations, including induction coils, hydraulic analogs, fluid mappers, and entire arrays of electrostatic generators and related devices. Recently he discovered a new line of phenomena, "electrospherics and magnetospherics," and has worked out a series of demonstrations accordingly. His latest paper, "Synthesized EMG Waves and Their Implications," is appearing in *The American Journal of Physical Medicine* and will be included in a forthcoming revised standard work on the subject of electromyography.

Many of his inventions came about purely by accident, but now that he is retired he feels that he has the time to devote to the necessary refinements. Former students the world over have the plans for many of his inventions and keep in touch with Moore concerning the progress they have made in improving upon and developing applications for his original work. Michigan's Department of Electrical Engineering continues to furnish him with a laboratory, where he can coordinate the three basic activities (thought, writing, experiment) that he finds essential to creative engineering.

Atmospheric effects on propagation at millimeter wavelengths (page 83)

E. E. Altshuler (SM) received the B.S. and M.S. degrees in physics from Northeastern University in 1953 and Tufts University in 1954, respectively. In 1960 he received the Ph.D. degree in applied physics from Harvard University. While at Harvard he held positions of teaching fellow and research assistant. Upon graduation from Tufts he worked for Sylvania, first for the Microwave and Antenna Department of the Avionics Laboratory and later for the Radar Department of the Missiles Systems Laboratory. In 1960 he joined the Electromagnetic Radiation Laboratory of the Air Force Cambridge Research Laboratories and was engaged in research on antenna arrays and spherical reflector antennas. In 1961 he left AFCRL to become director of engineering at Gabriel Electronics, where he supervised the development of a product line of microwave antennas. In 1963 he returned to AFCRL as chief of the Transmission Branch of the Microwave Physics Laboratory and directed research programs on ELF and VLF propagation through the earth. As chief of the Millimeter Wave Branch of the Microwave Physics Laboratory, he now supervises propagation and environmental research at millimeter wavelengths.

In addition, Dr. Altshuler has been a lecturer at Northeastern University's Graduate School of Engineering since 1964. He is a member of URSI (Commission VI), Sigma Xi, Sigma Pi Sigma, and RESA.

V. J. Falcone, Jr., was born in Boston, Mass., in 1935. He received the B.S. degree in physics from Boston College in 1957 and the M.S. degree, also in physics, from Brandeis University in 1959. While at Boston College he held a research assistantship in nuclear physics, and while at Brandeis University he was a teaching assistant and held an IBM research assistantship. In 1959 he joined the Astro-Surveillance Sciences Laboratory of the Air Force Cambridge Research Laboratories, where he was engaged in research involving the infrared region of the spectrum. In 1961 he entered the U.S. Army and was assigned to the Nuclear Branch of the Ballistic Research Laboratory at Aberdeen Proving Ground, where he worked on satellite calibrations. In 1962 he was transferred to the Watertown Arsenal, where his research was on the dynamic stress concentration in an elastic plate with inclusions. After leaving military service, he returned to the AFCRL, where he initially worked on ionospheric perturbations. Now a research physicst in the AFCRL's Microwave Physics Laboratory, he is investigating atmospheric and solar phenomena at millimeter wavelengths.

Mr. Falcone is a member of the American Physical Society, the American Institute of Physics, Sigma Pi Sigma, and RESA.

K. N. Wulfsberg (M) was born in Elbow Lake, Minn., in 1915. He received the B.E.E. degree from the University of Minnesota in 1942 and the M.S. degree in applied physics from Harvard University in 1947.

Mr. Wulfsberg was commissioned in the United States Navy in 1942 and served on active duty until 1946. He joined the Air Force Cambridge Research Laboratories in 1947 and has worked in the areas of signal integration, digital communication, ground-to-air data links, and ground-to-air ionospheric scatter communication. At the present time he is a research engineer with the Millimeter Wave Branch of the AFCRL's Microwave Physics Laboratory, where he is engaged in programs for studying the effects of the atmosphere on propagation at millimeter wavelengths using radiometric techniques. In addition, he is conducting high-resolution solar and planetary observations using the AFCRL 29-foot millimeter-wave antenna. Mr. Wulfsberg is a member of Eta Kappa Nu.

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Men, machines, and

In today's computer we have a device in which meaning has its narrowest behaviorist sense—the precise linking of response with stimulus. Steps have been taken toward giving computers a picture of the world, but the results so far have been more startling than useful

> "When we listen to a person speaking or read a page of print, much of what we think we see or hear is supplied from our memory. We overlook misprints, imagining the right letters, though we see the wrong ones; and how little we actually hear, when we listen to speech, we realize when we go to a foreign theatre; for there what troubles us is not so much that we cannot understand what the actors say as that we cannot hear their words. The fact is that we hear quite as little under similar conditions at home, only our mind, being fuller of English verbal associations, supplies the requisite material for comprehension upon a much slighter auditory hint."
> —William James.[1]

Men communicate with each other by natural language and with machines by computer language. Building a bridge between these forms of communication has proved difficult, possibly because of misunderstandings about the nature and use of each kind of language. This article points out that until people succeed in storing in a computer considerable areas of human experience, they are not likely to make a computer interact usefully with natural language.

Language is a powerful tool by means of which men communicate. Computer languages are powerful tools by means of which men use machines. It has been suggested frequently that the gap between the natural languages of men and computer function should be bridged for such purposes as machine translation or information retrieval. It has proved difficult to carry such suggestions through to any useful end. This may be the result of misunderstandings concerning the nature and use of machine languages and natural languages.

The functioning of a computer is an example of meaning in a sense that would delight a behaviorist psychologist. At any moment, the physical state of the computer is described by various electric and magnetic fields, which are either positive or negative, or on or off, as well as by whether certain switches are open or closed. The computer proceeds deterministically from one state to another in a manner dictated by signals stored in its memory units, whether these be cores, tapes, or cards.

The output of the computer is likewise completely determined by the state of the computer and by its interconnections, whether they be physical or specified by the program.

The input of the computer is provided ultimately by a human being. The human being wants to make the computer process data in a way that is specified by him, to some end that he hopes to achieve. The computer certainly has a meaningful relation between the output and the input in that the output depends on the input and the internal state of the machine. The human user has a somewhat different criterion of meaning in mind. To the human user, the computer's output is meaningful in its relation both to the input—and to his intentions. He doesn't want to know about the computer's detailed and essential internal operations unless he has to. In order to get the output he desires, the human user feeds into the computer both data and a program of instructions expressed in what is called a programming language.

Even to the experienced user equipped with programming manuals that purport to tell how to make a computer system do a specified thing, the problem of using a large computing system has an element of psychological study in it. This is not the case because the meaning of instructions in a computing language is obscure to the computer, but because it may be obscure to the user. Such obscurity arises in two ways.

First, in order to make computer languages easy to learn and use, their designers make them to some degree resemble mathematics, or English, or both. Fortran, for instance, resembles mathematics and simple English. This resemblance makes Fortran easier to learn than it would be if it resembled nothing that the user had ever encountered before, either in the symbols used or in their relation to one another. However, the resemblance of Fortran to mathematics and English tempts the user to guess at the instructions needed to produce the intended output rather than to look them up in the manual. Or, even when the user does look an instruction up in the manual, he may misunderstand it. That is one way in which a user may communicate to the computer a statement whose meaning is perfectly explicit to the computer, but is misunderstood by the user.

Another source of trouble—or, if we wish, misunderstanding—arises through the complexity of controlling the computer or through malfunction, which is not infrequent. The linkage between computer input and output is a deterministic mechanism whose functioning

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John R. Pierce

Bell Telephone Laboratories, Inc.

can be described in terms of its states and the inputs. The program acts on the mechanism of the computer through several levels of language. There is the machine language, whose instructions do simple, understandable things in transferring digits in and out of specific memory locations, and in performing certain logical operations, as well as certain input and output operations, such as reading from or writing onto tapes or disks, or controlling printers.

Once removed from the machine language is the operating system and an assembly language. Together, these enable the user to cause the computer to do humanly useful but complicated sequences of operations by means of a few instructions. The operations include input and output operations and the assignment of places in the computer memory in a symbolic manner rather than by actual location. They also include certain diagnostic functions—telling a programmer that he has given a meaningless, and therefore illegal, instruction, or telling him of certain malfunctions of the machine comprising the hardware and software that make up the operating system.

Although some programs are written in assembly language, most are written in a higher-order language. By means of a compiling program the computer goes from the instructions in the higher-order language to a machine language code, which, the programmer hopes, will make the machine do what he desires.

It is not uncommon for there to be a number of layers of language, one on top of another. For instance, Trac statements may be interpreted or "translated" into Fortran statements by a program written in Fortran. The resulting Fortran program will then be compiled into assembly language, and the assembly language and the operating system will then produce the required machine language instructions to accept input, to perform the necessary logical and arithmetic manipulations, and to supply output.

Computing machines are often fallible, and hardware faults are common, but human beings are even more fallible when faced with the complicated task of programming a computer. This exists at several levels.

The fallibility of humans

One common fallibility is called errors in logical design. This means that the designer himself did not understand the hardware that he built. Sometimes what it actually does isn't what he thinks it will do. Either he didn't ask what would happen in all contingencies, or he made a mistake in judging what the hardware he designed would do. Logical faults—that is, incomplete knowledge of the basic hardware—can be overlooked and can remain obscure for a long time, because sometimes the so-called malfunction, which is really a malfunction of the designer, is apparent only under unusual circumstances.

Up through the layers of language there are other traps for the programmer. The programmer thinks he knows what he wants various instructions and sequences of instructions to do, and he thinks he knows how to make the machine carry out this intent. But often he is mistaken. The instructions always have a clear meaning to the computer; they cause it to do something completely mechanical and logical. But this may not conform to the desires or logic of the programmer. For instance, in a new computer system too close to home for the event to be entirely amusing, an innocently intended instruction in a program made the operating system inaccessible to the computer, so that the machine was inoperative for several hours. This must have been what the machine had been asked to do, but the programmer hadn't meant it that way. He didn't fully understand the nature of the machine and its operating system and its language. In a case such as this it is pretty hard to find out just where in all the complexity the mistake lies.

How does the advanced programmer deal with the problem of designing layer on layer of computer languages in such a way that he can predict the outcome of computer operation? Obviously, he doesn't, in a high-order language, try to trace the consequences of an instruction right through all the hardware of the machine. Rather, he works with what one might call levels of meaning. In writing a language over an assembly language, for instance, he assumes that he understands the implications of the assembly language completely, that is, what it will do to the machine under all conditions. Similarly, if he writes a language to be translated into Fortran, he assumes that he understands the consequences of any Fortran program in the same way that the machine will carry them out. The programmer works pretty much with native ingenuity coupled with bright ideas, many, if not all, of which can be described by the word "algorithm." An algorithm is merely a completely explicit procedure at any level for making a computer do your bidding.

Beyond ingenuity and an assortment of algorithms, the computer expert has various sorts of formal mathematics, which can help him to see the consequences of his actions. Presumably, the Lord God Almighty can see immediately the consequences of any assumption or action, and so he doesn't need the notation and the operations of mathematics in order to help him trace consequences out. Man is pretty poor at seeing consequences. Thus, to the hardware man, Boolean algebra can be of great help, for it enables him, through mechanical mathematical operations, to realize certain logical functions of input economically by means of specific hardware.

On the more complicated levels of overall machine design and of programming, there are also some useful mathematical tools. These include automata theory and mathematical linguistics. By giving simplified models of the essential aspects of a computer, automata theory tells one what one can do with machines, and hopefully gives a clue as to how this can be accomplished. Mathematical linguistics teaches how to formulate rules of syntax in the most elegant manner. It is an aid in designing languages so that in going from one level of language to another the computer will more often do something that was intended by the programmer rather than something that he accidentally or involuntarily put into the program without understanding its nature and consequences.

Although it is easy to get disconnected from this reality, it is clear that reality in the computer is meaning in the sense of explicit physical events and sequences of events in the mechanism of the machine and the output that these produce. In the solving of even a simple problem these events are simple in themselves and in their immediate interactions, but the chain of events is too long and highly interrelated for a human being to grasp. The problem of the programmer and the program designer is to present the user with a language that is just as meaningful, in that a given input always has a precise output, but a language of which the programmer can grasp the consequences. Thus, a desired input language is one in which the programmer seldom makes the mistake of asking for something he really didn't mean, although he doesn't know just what the computer does step by step in carrying out his intent.

There can scarcely be one ideal programming language; programming languages are designed for various problem areas. And within a sizable problem area, a single, ideal programming language that is perfectly understandable with a modicum of study is perhaps unattainable. Even if we could attain it, programmers would still be so fallible as to make mistakes. Thus, in a chosen field, one approaches some practical level of usefulness in which programs usually do what one would expect after a reasonable study of the programming manual, and in which the language is so well adapted to human needs in a usefully broad area that the programmer seldom makes mistakes in terms of what is written in the manual. It is certainly desirable to study ways of writing languages whose consequences can be completely described in a manual of reasonable length, but this is obviously not necessary for the satisfactory use of computers, and it has scarcely been attained at the present time.

I have now come almost to the end of what I want to say concerning computers, computer languages, and the use of these languages and computers by human beings, and here I would like to philosophize a little.

First, a behavioristic sort of meaning is paramount in dealing with computers. The computer always does something. What it does depends on how it was built—whether the builder understood it or not. The programmer has some intent that seems clear to him. If it is clear to him and the computer doesn't understand him (that is, it doesn't process his data as he wished it to), the fault is either that he didn't understand the manual, or that the manual was at fault and failed to predict what the consequences of a given program would be, either through a failure of software design at some level or through a logical error of the designer of the machine.

In computer language, grammar and syntax are tools in relating the operation of various parts of the computer to sequences of humanly useful symbols. It may be that human beings are worthy of study for as long as man exists, because as long as man exists, human beings will surround him. Computers are worthy of study because they do useful things for man and because man wants to make better computers that will do even more useful things. Hence, in human terms, the mathematical tools necessary in the design and use of computers are important only insofar as they enable us to design better computers or to use computers better. Few mathematicians are interested in improving real computers. Mathematicians do, however, become fascinated by the branches of mathematics that seem to be pertinent to computers, and through this fascination they may sometimes produce results useful to computer designers and programmers—but they may not. Those interested in designing, understanding, and using computers will cast a wary eye at the mathematically inclined, and ask whether a given piece of work has really advanced our ability to build and control computers.

MAN

So far I haven't said anything about artificial intelligence, and I don't intend to say much. Many early computer enthusiasts thought that computers should resemble human beings and be good at exactly the tasks that human beings are good at. This is like drawing a vehicle by a steam man between the shafts, or designing an airplane that will light on a tree. It is facing the future with one's back squarely toward it. Progress with computers has come through employing their useful potentialities, not through trying to make them conform to human behavior. The new and useful tasks that computers do are often far more complicated than the useful tasks computers did in the past. Hence, computers continually look more "intelligent." It would be foolish to set any limit to the complexity of the tasks for which computers may some day prove useful. But the sort of performance the artificial intelligence enthusiasts have worked toward hasn't proved useful. Computers have been miserable at theorem proving, music composing (at least we don't enjoy their compositions—maybe computers do), chess playing, and general pattern recognition. In view of the tremendous usefulness of computers, all I can say about the failures in these fields is, so what?

Another aspect of artificial intelligence I might describe as the easy way out. Some people believe that by combining an element of randomness with a so-called heuristic strategy, one can get the computer to solve problems better than through an intensive exercise of human ingenuity toward a particular goal. It just hasn't worked out that way.

The human use of human language

We now come to a quite different field, the human use of natural or human language. Here it is hard to get started. Although we all have implicit knowledge of human language, in that we are able to produce, use, and understand it, no one understands human language explicitly, as we can, at least in principle, understand a computer language in connection with a computer. The human world of our apprehension, thought, and action is in computer terms a high-level world. It is clearly many levels removed from neuroanatomy and neurophysiology. Our understanding of neurophysiology and neuroanatomy is small but increasing, but we are certainly not at such a point that we can either work upward and explain higher-level function explicitly in terms of function at the neural level or work downward and find out just how high-level instructions result in appropriate physical actions. Most human behavior, including language function, has to be tackled at a higher level.

It is tempting to liken the psychologist to a computer programmer equipped with a very imperfect programming manual, and with no really useful insight into the internal structure of the machine. Being denied access to the machinery, the psychologist may seek understanding in terms of input and output. His manual relating these includes experimental results, common knowledge, and folklore. It is perforce incomplete, and it is almost certainly wrong. This wrongness may in some instances be of a very fundamental kind, or it may be a wrongness engendered simply by the fact that different human beings are different whereas different computers of the same model are presumably the same.

If this were all there was to it, a study of human linguistic behavior (or, indeed, of human behavior) might well start with a search for the syntax of human language, to be followed by an exploration of the effects of well-structured sentences on human beings. Alas, things aren't that easy.

My attention was first drawn to linguistic problems through Claude Shannon, with whom I was closely associated while he was inventing information theory. Information theory tells us that messages from a stochastic source can be efficiently encoded if we take into account the probabilistic constraints on the source in producing symbols. This led Shannon to produce, by probabilistic means, sequences of symbols that resemble English words, and sequences of words that resemble English text, as shown in the following examples:

1. Zero-order approximation (symbols independent and equiprobable):

XFOML RXKHRJFFJUJ ZLPWCFWKCYJ FFJEYVKCQSGHYD QPAAMKBZAACIBZLHJQD.

2. First-order approximation (symbols independent but with frequencies of English text):

OCRO HLI RGWR NMIELWIS EU LL NBNESEBYA TH EEI ALHENHTTPA OOBTTVA NAH BRL.

3. Second-order approximation (digram structure as in English):

ON IE ANTSOUTINYS ARE T INCTORE ST BE S DEAMY ACHIN D ILONASIVE TUCOOWE AT TEASONARE FUSO TIZIN ANDY TOBE SEACE CTISBE.

4. Third-order approximation (trigram structure as in English):

IN NO IST LAT WHEY CRATICT FROURE BIRS GROCID PONDENOME OF DEMONSTURES OF THE REPTAGIN IS REGOACTIONA OF CRE.

5. First-order word approximation. Rather than continue with tetragram, . . . , *n*-gram structure, it is easier and better to jump at this point to word units. Here words are chosen independently but with their appropriate frequencies.

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6. Second-order word approximation. The word transition probabilities are correct but no further structure is included.

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From the point of view of information theory, it is interesting that there are probabilistic constraints on English text. By observing these constraints, we can encode English text for economical transmission. But it was easy to jump from Shannon's experiments to false or unrewarding conclusions. Because Shannon considered probabilistic models that were Markov processes or else finite-state machines, one might conclude that a Markov process or a finite-state machine could, in principle, produce any English sentence. Chomsky denounced the fallacy of any such models almost before they were proposed.[2]

There was another unrewarding conclusion that Shannon's experiments made it easy to jump to. This was that somehow syntactic rules must be not only necessary to, but central to, the human use and understanding of language. Linguists set themselves the task of devising a grammar that would produce all well-formed (I guess that means "correct") English sentences and would not produce any but well-formed English sentences. Whatever may be said concerning the ultimate success or failure of such a program, the real question is that of its relevance to the human use of language.

Here we must distinguish several areas of importance. One, for instance, is the teaching of a language to adult foreigners. Successful teachers will say that it is important to give a student the sounds of a language and its structure, and that he will then acquire its vocabulary.

But the structure that a teacher gives to his students is not a complete description of how to produce all well-formed utterances and none but well-formed utterances. This appears to be beyond the power of the most complicated grammars that have been devised, for English, for instance. And those grammars are so complicated that they are of little use in teaching English.

The grammar the language teacher needs is rather like tips for playing golf or tennis, or rules for spelling.

What is needed is reminders that can be remembered and used by human beings; that is, useful rules to supplement and guide the acquisition of an implicit knowledge of the language.

It isn't easy to arrive at such an incomplete grammar. We all know foreigners who, though capable of quoting endless grammatical rules, make mistakes in speaking English. However, many natives who can enunciate few if any grammatical rules can speak flawless English.

Another possible use of a grammar of the English language would be in instructing computers how to do things. It is said that modern linguistics has contributed greatly to the writing of compilers and the devising of machine languages. If this is so, it shows merely that syntax is very important in machine languages. Advanced linguistics has not enabled computers to process natural language in the sense of translating from one language into another, or of acting on instructions given in natural language. The reason for this is easy to see.

It is plausible that meaning rather than grammar is the essential element in the human use of human language. No one can argue that grammar isn't there. However, I can say that I've heard a dean of engineering talk perfectly sensibly and understandably for half an hour without uttering a single well-formed sentence. I can also argue that efforts such as that of Katz and Fodor[3] to bring meaning in through the back door of grammar seem to lead more to increased complexity than to added enlightenment.

The machine as translator

The failure of a grammatical approach to the problems of natural language is well illustrated in attempts at machine translation. Here one can go a considerable distance in translating from one language to another closely related language simply through dictionary lookup. There can be a good deal of intelligibility in the output, but it is poor in two ways. Because many words are used in several senses or have several meanings, through dictionary lookup one often gets either the wrong word or an assortment of words. Coupled with this is a strange word order in the output which is often baffling.

It may be possible to learn to make some sense of text translated simply through dictionary lookup, but one would like to do better. The approach of machine-translation people has been to try to select words and to amend the word order by using grammatical constraints. In any practical sense this hasn't worked. Machine translation still is chiefly a sort of gobbledygook. The trouble becomes clear when we turn from machine translation to machine parsing of sentences.

The machine parsing of English sentences by Oettinger and his associates,[4] as well as by others, has shown that almost all English sentences are syntactically ambiguous, even with the most powerful, unwieldy, and generally useless grammars that linguists have been able to devise. Thus, we all know instantly the meaning of "Time flies like an arrow," but a computer may well conclude that there are time flies who like an arrow, or that someone is being instructed to time flies in the same manner as an arrow would time flies. There are other grammatically sensible interpretations of this sentence as well. The diehards ceaselessly try to amend their grammars with new rules and with semantic markers. Some disgusted spectators have turned in other directions.

Experiments by Miller and his associates have shown that sentences formed according to syntactic rules which result in a structure resembling that of natural English sentences are more easily understood than sentences formed according to equally rigid rules that give sentences that don't much resemble English sentence structure. This is not surprising. Experiments by McMahon, Slobin, and Gough[5] also seemed to show sentences with a simple grammatical structure to be more quickly apprehended than sentences that conveyed what seemed to be the same meaning through a more complicated grammatical structure, such as the passive voice. This opened up an interesting line of experimentation, but further experiments should make one wary of conclusions based on grammatical theories alone.

Indeed, human judgment in the area of grammar seems to be influenced more by meaning than by syntactical structure. Some years ago S. M. Pfafflin[6] carried out an experiment at the Bell Telephone Laboratories with computer-generated sentences of simple and acceptable syntactic structure. She asked naïve subjects whether or not these sentences were "grammatical." The subjects clearly based their judgments on meaning as well as on syntax. If they could make sense of a sentence they judged it to be grammatical; if not, not. The more intelligent and ingenious subjects could think of and accept more unusual meanings than duller subjects, and they judged more sentences to be grammatical. This makes it seem plausible that the idea "grammatically correct" has meaning and use to ordinary human beings only in connection with meaningful sentences.

This corresponds to my introspective view of my reaction to a sentence, or even a nonsentence, of human origin. My immediate reaction is, what does he mean? When human, or indeed computer speech, is poorly intelligible, my mind races to attach a meaning to the utterance, and when I succeed the sounds become "clear." When I try to parse a sentence, I already know what the sentence is saying—or I can't parse it.

Thus, it appears that syntax does not play the same sort of role in the human use of human language that it plays in the computer use of computer language. It is natural for a computer to parse a statement as a very first step in making use of it. A man cannot parse a statement in natural language until he knows something about the meaning of the statement. Further, errors in syntax usually change the meaning (to the computer) of a statement, but they do not necessarily change the meaning to a human being of a statement in natural language.

No doubt syntax comes into the understanding of speech, but meaning seems somehow to come first. And this meaning includes our knowing what subject is being talked about and knowing something about the subject, not just context in the sense of association of words in a sentence or on a page.

In experiments carried out at the Bell Telephone Laboratories by J. S. Sachs,[7] subjects who were queried about material they had heard or read remembered chiefly the content rather than the grammatical structure or the choice of words. This was true even when they were presented with a statement embodying the content of the last sentence they had been exposed to and were asked whether or not this was identical with that last sentence.

Subjects were prone to say that the test statement was identical with the last sentence if the meaning was the same, even though some words had been replaced by synonyms.

Where do we go from here?

It is all very well to say that meaning is central to the use of language, but this tells us neither how to define meaning, nor how to make use of it. Where do we go from here? That depends on what we want to do.

If we want to use natural language as an input to machines, it means that in some very real sense the machine must understand what the language is saying in the same sense that a human being does. This is the position that V. K. Yngve reached after years of work in computational linguistics. As he has written,[8] "Work in mechanical translation has come up against a semantic barrier. We have come face to face with the realization that we will only have adequate mechanical translation when the machine can 'understand' what it is translating and this will be a very difficult task indeed . . ."

Human beings get at the content of sentences because they have an internal map of the world to which the sentences are relevant. This somehow enables them to arrive at the content of the sentence whatever its grammatical form, and even when it is ungrammatical. As I have already observed, it even enables a person to arrive at the content of a sentence when some words are not clearly enunciated or clearly heard. This is because the person somehow checks the sentence against what he already knows about the world or the subject under discussion.

Fred Thompson[9] was able to incorporate a little of this in DEACON, a machine system for giving naval information in response to simple English inquiries. For instance, DEACON is able to understand that in the phrase "Boston Navy Yard," the meaning is not the yard of the Boston Navy, but the Navy Yard at Boston. The machine arrives at this conclusion, not through linguistics, but because someone has stored in it the information that there is a Navy Yard at Boston whereas Boston Navy is an undefined and therefore meaningless term.

We may hope that in the future it will be possible in some way to give machines enough knowledge of a subject other than their own construction to enable them correctly to interpret natural-language statements in some limited field of interest.

Indeed, this has been done in some degree in many modern computing languages and operating systems. The computer will accept statements with some range of syntax and interpret them plausibly. The computer has stored away in it humanly useful responses to certain errors in programming to which human beings are generally prone. These include such admonitions as "line 10 is not a statement" (which means it is not syntactically allowable); "in line 15, *N* is not defined" (which means nobody has put in a value for it or an equation defining it); "what" (which means that the user has done something wrong at that place in the program).

The problem of enabling a computer to use natural language as an input by incorporating in it some sort of map of even a portion of the world is difficult and ill-understood. Man's knowledge of the world enables him to make use of ungrammatical sentences when the meaning is clear. Man can also interpret correctly, that is, give correct operational meaning to, sentences that use words in a "broad" sense. Thus, we have no trouble with "open the door," "open the box," "open the fan," even though the particular physical operations are different. Moreover, if I were handed some strange, unnameable but "openable" object and told to open it, I believe I would have a fair chance of succeeding.

It almost seems as if man uses an ability to coin apt but (to him) new phrases or word usages, which, in a context of particular things and actions, will almost always be terpreted correctly. Thus, "open" seems to be associated with making the inside accessible from the outside, and such words as "cut" and "tear" with actions that can be means of providing such access. "Open the jalousie," or "tear" or "cut the ottoman open" are interpreted easily enough when such objects are before us or known to us, whether or not we have previously associated the word "open" or the idea of opening with them.

However he is able to do it, somehow, man can respond to instructions phrased in broad concepts. If the computer is to respond to the same sorts of instructions that man responds to, it must somehow perform this miracle.

Today we have in the computer a device in which meaning has its narrowest behaviorist sense: the precise linking of output with input, of response with stimulus. The computer is dependent on and susceptible to syntax. The computer has little or no picture of a world outside itself, to use in testing or interpreting statements or in ascertaining the precise meanings of ambiguous words.

Man, who lives in the world and has some knowledge of it, jumps at content or meaning before he fully resolves syntax, if indeed he does, and he interprets words such as "open" correctly in a wide variety of contexts.

Some steps have been taken toward giving computers a picture of some portion of the world.[10] So far, the results have been more startling than useful. Someone may well go much further and be able to put into computers maps of considerable areas of human experience or human knowledge. But until people succeed in doing this in a satisfactory way, they are not likely to succeed very well in making computers interact usefully with natural languages.

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Railroad electrification: past, present, and future

History of systems in the United States

Railway electrification in the United States dates back more than 70 years. It reached its peak during the 1930s, but, with the advent of diesel and diesel-electric locomotives, it declined markedly from a peak of more than 4000 km of electrified trackage to about 2900 km in 1966

Gordon D. Friedlander *Staff Writer*

Although early efforts to propel railway vehicles by primitive batteries date back as far as 1835, the first successful application of electric traction probably occurred in 1879, when a locomotive designed by Dr. Werner von Siemens was operated at an exhibition in Berlin. This priority may be in some dispute, however, since Thomas Edison experimented with an electric locomotive at about the same date, and Steven D. Field was also testing such a device at this point in time. George Westinghouse, the genius of American railways, was another pioneer in this developmental effort. The story of railway electrification is one of epic proportions both in the United States and elsewhere. The first installment of this three-part series is concerned with the historical development of electric railway systems in the United States up to the present time. The second chapter will discuss the advent of the diesel locomotives and their impact upon electrification, automatic signal and safety features, and the present and future prospects for the electrification of proposed rapid transit systems. The final installment will deal with the development of the European systems.

They gave him his orders in Monroe, Virginia
Saying: "Sam, you're a-way behind time;
This is not number 12, it's old 97,
You gotta bring 'er into Spencer on-time."
—*from "The Wreck of Old 97"*

By the 1870s, the "high iron" of U.S. railroads had spanned the Rocky Mountains, crossed the continental divide and, threading along switchbacks and defiles, through the snowsheds and long tunnels of the Sierra Nevada, and across precarious high wooden trestles above deep gorges, finally plunged down toward the green valleys of central California and the seaport cities on San Francisco Bay and the Golden Gate.

Thus, continuous ribbons of steel were forged from coast to coast. It was an era perhaps best described by the stirring lines from *The Empire Builder*: "Westward the Star of Empire takes its way, and valiant men have thrust our frontiers to the setting sun."

The turn of the century witnessed the traditional "iron horse" steam locomotives of the romantic period of railroading—the 2-8-2* "Mikado," the 4-8-4 "Northern," and the giant 2-6-6-2 compound Mallet locomotives—chugging "double-header" along the two percent grades of the Rockies and the Sierras at the head end of mile-long freight trains.

In the East, Midwest, and South, the great systems, such as the Pennsylvania Railroad, New York Central, Baltimore & Ohio, Southern Railway, Union Pacific, and the Nickel Plate, were consolidating their routes.

As the major cities grew in size and population density, many people realized that the fumes, soot, and noise produced by the steam locomotive were not well adapted to center city operation, and that a better answer for railroad traction would have to be found.

George Westinghouse and the street railways[1]

As early as 1884, the first street railway (tram) line—the Union Passenger Railway of Richmond, Va.—utilizing an overhead electrified trolley wire, was designed and built by Thomas J. Sprague, a former protegé of Thomas Edison, who also organized the Sprague

* These numerical designations classify steam locomotives by the number of their wheels. Thus, the 2-8-2 "Mikado" class of freight locomotive indicates that the engine has two pilot wheels (forward), eight drive wheels, and a trailer truck of two wheels.

Electric Railway and Motor Company to equip the Richmond system.

The electrification of street railways captured the interest of George Westinghouse—already noted for his invention of the air brake—particularly after he watched Edison's strange little electric locomotive hum around the laboratory at Menlo Park. In the early 1880s, electricity was showing promise as a power source, but there were many problems involved in the application of direct current as a means of railroad locomotion over long distances. At that time, dc generators could not provide adequate power over stretches of more than 2 km from a generating station. And to supply a street railway of any practical length would have required the installation of numerous wayside generating plants at a prohibitive cost.

Then, a brilliant electrical engineer, Guido Pantaleoni (employed in Westinghouse's Union Switch & Signal Company), during a trip to Europe, described to Westinghouse by letter a system for distributing alternating current that was the collaborative invention of Lucien Gaulard (French) and John Dixon Gibbs (English). One of the devices employed was a transformer that could step ac voltage either up or down.

Westinghouse obtained an option on the novel system and, by late 1885, several of the transformers were set up at the Union Switch & Signal plant, where they were redesigned and modified to achieve the basic features that have been used ever since that time.

The new transformer provided the key to the ac system—and the formation of the Westinghouse Electric & Manufacturing Company.

From 1888 to 1892, Westinghouse worked with Nikola Tesla, the Yugoslavian electrical genius, on the development of a polyphase ac system to be used in conjunction with the Tesla ac motor. During this period of experimentation, however, Westinghouse developed the rotary converter for the conversion of high-voltage alternating current to direct current for use in conjunction with double- and single-reduction railway traction motors. (Up to this time, the third-rail conductor was generally employed by that company's engineers.)

With alternating current, it was easy to meet the high-voltage requirements of short-run municipal street railways, but for long-distance interurban runs there would be problems. Even with the introduction, in 1894, of a 3-phase German traction system utilizing two overhead wires, the transmission limitations of 3000–4000 volts were known to be insufficient for extensive electrified systems. Improvements in the technology would have to be made. And they were . . .

In 1895, Westinghouse entered a joint venture with the Baldwin Locomotive Works (Philadelphia) to design and build electric locomotives and to promote the concept of electric traction for trains entering metropolitan areas. Actually, the move was prompted by a similar arrangement between the General Electric Company and the Schenectady Locomotive Works to design, construct, and equip a new rail line in Baltimore.

FIGURE 1. One of the Pennsylvania Railroad's Class DD-1 articulated, dc locomotives, equipped with third-rail conductor shoes. These 142-tonne, 1900-kW engines were put in the tunnel service between Pennsylvania Station (New York City) and Manhattan Transfer (New Jersey) in 1910. They could also be used for hauling passenger cars through the East River tunnels to the Sunnyside Yards (Queens) for maintenance, servicing, and in train makeup.

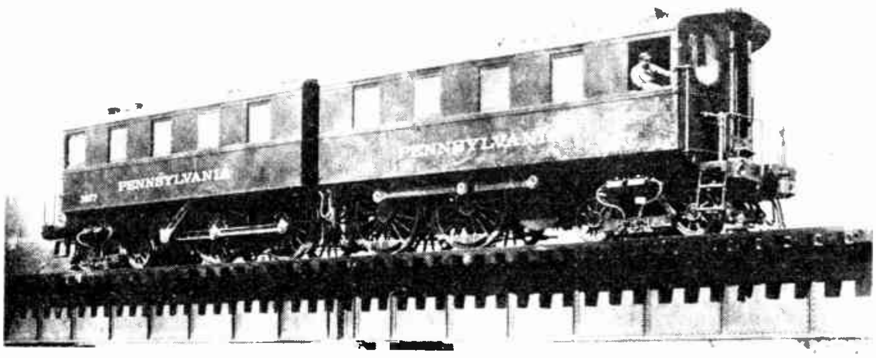


FIGURE 2. Two of the Pennsylvania's early experimental locomotives: right, the FF-1 freight engine with four 3-phase motors; below, the L5 passenger locomotive, which contained four single-phase motors.

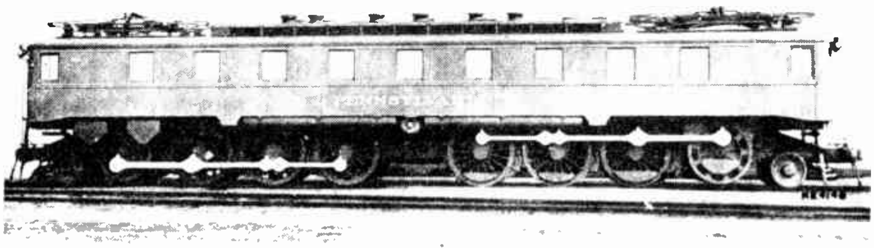
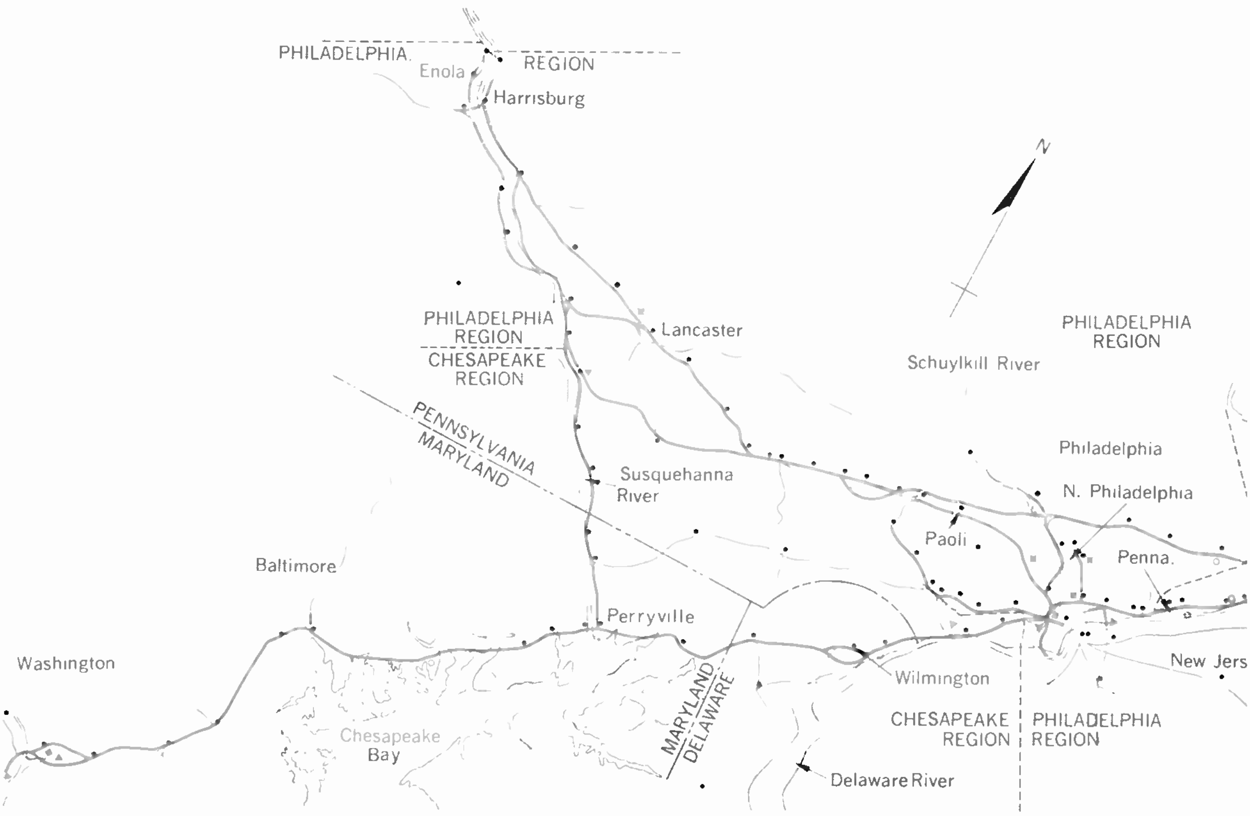


FIGURE 3. Map showing the Pennsylvania's present-day electrified territory, which comprises about 660 route-miles. It encompasses the routes from New York City to Washington, D. C. (to the south), and from Philadelphia to Enola and Harrisburg, Pa. (main line to the west).



Belt Line of the Baltimore & Ohio. This was the first trunkline electrification in the United States. Constructed in Baltimore, Md. (1895), it ran for 3.63 route-miles (5.8 km)—including a 7300-foot-long (2200-meter) tunnel. This service was installed primarily to eliminate the noise, soot, and noxious fumes produced by steam locomotives in the tunnel section and in the heart of the city.

Electrification on the PRR

The first use of electric traction on the Pennsylvania Railroad was an 11-km experimental dc system, which was installed and placed in service between Burlington and Mount Holly, N.J., in 1895.[2] This was followed by a 95-km-long 600-volt dc third-rail electrification between Camden and Atlantic City, N.J. Inaugurated in 1906, it was the longest line to be changed from steam to electric operation up to that time.

The initial electrification of the present-day electrified territory of the railroad was the completion, in 1910, of a 600-volt dc third-rail system designed to haul passenger trains through the Hudson River and East River tubes to and from Pennsylvania Station in New York City. This line extended about 25 route-miles (40 km), from Manhattan Transfer (New Jersey) to Sunnyside (Queens). Figure 1 shows one of the early Baldwin–Westinghouse Class DD-1 dc locomotives used in this first phase of tunnel service.

After the initial experimentation with various types of electric locomotives (Fig. 2) and the use of direct current in the New York tunnels, it was decided that alternating current would provide a more efficient and economical system. Although no suitable on-locomotive rectifying apparatus was available at that time, 25-Hz energy could be obtained; thus, the use of a single-phase 25-Hz system in conjunction with locomotive and multiple-unit car equipment having series-wound ac traction motors was considered to be a workable compromise to equipment with dc traction motors.

The Philadelphia–Paoli line. According to W. E. Kelley, assistant electrical engineer of the now Penn Central, the actual beginning of the present-day 11 000-volt, 25-Hz system of the PRR, which encompasses the territory from New York to Washington, D.C., to the south, and to Enola and Harrisburg to the west (Fig. 3), was the completion of the 32-km Philadelphia to Paoli suburban line electrification in September 1915. This electrification was necessary as the first step in eliminating the acute problem of suburban passenger traffic congestion in the Philadelphia metropolitan area. With this in mind, the service was extended to Chestnut Hill in 1918, to West Chester and Wilmington (Del.) in 1928, and to Norristown and Trenton in 1930.

For the Philadelphia–Paoli run, 93 all-steel multiple-unit cars (some of which are still in service) were placed in operation. The equipment of each car consisted of two 168-kW Westinghouse single-phase, air-blast-cooled repulsion-starting motors mounted on one truck. Power was supplied from an 11 000-volt catenary contact system carried on cross-wire bridges. Automatic acceleration was provided with the control, together with automatic multiple-unit electropneumatic brake equipment.

The motors, which were connected in series, were started and operated, up to speeds of about 24 km/h, as repulsion motors, with the auxiliary field, the armature, and the main field in series (Fig. 4). With these series connections, the armature was short-circuited through resistance. The resistance was also inserted in series with the motors on the first step and was cut out on the second step. The third step changed the connections to energize the auxiliary field from one portion of the transformer and the armature and main field, connected in series, from another portion of the transformer, thus affording doubly fed connections. The armature short circuit was removed when the motors were operating with the double feed, and subsequent steps in the control were obtained by increasing the motor voltages.

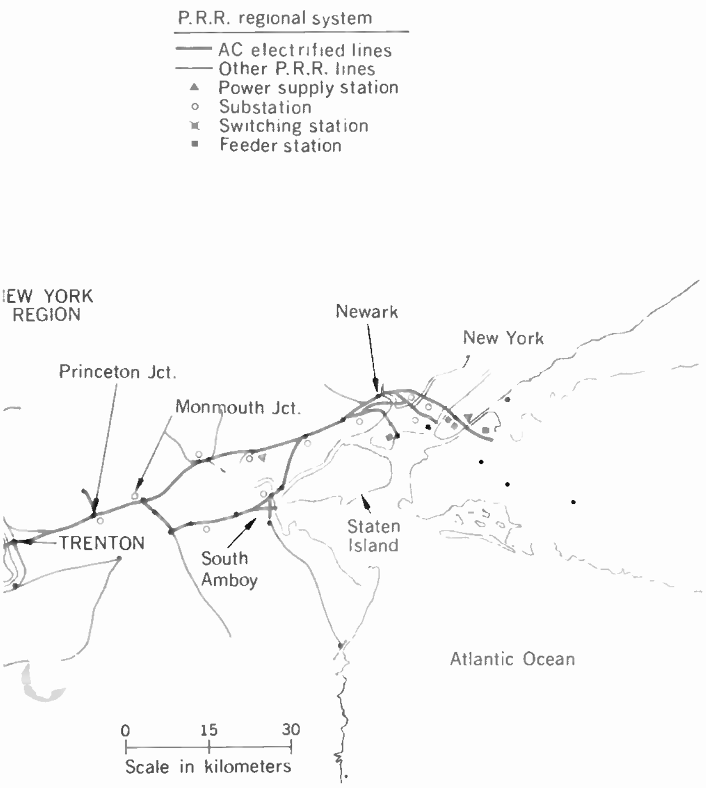
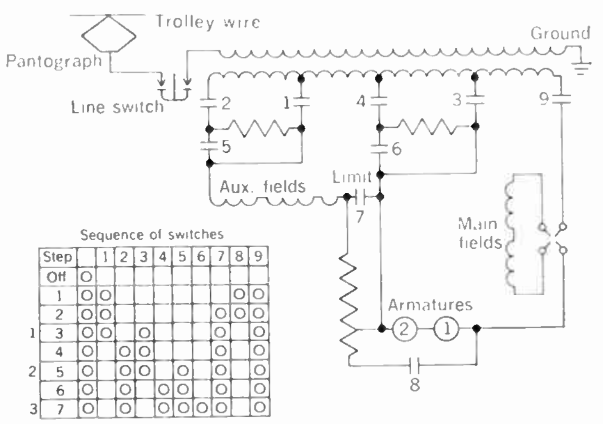


FIGURE 4. Schematic diagram of the repulsion motor connections on the early PRR multiple-unit cars.



	Step		1	2	3	4	5	6	7	8	9
	Off	O									
	1	O	O							O	O
	2	O	O						O	O	O
1	3	O	O		O				O		O
	4	O		O	O				O		O
2	5	O		O	O		O		O		O
	6	O		O		O	O		O		O
3	7	O		O		O	O	O	O		O

Power for the control system was supplied from a motor-generator set, and the movement of the master controller handle to the right or to the left energized the proper control circuit for the forward or reverse movement of the train. Train acceleration on straight, level track was approximately 0.5 m/s² up to a speed of 48 km/h. Top speed was about 100 km/h.

Electrification at the present time. The 25-Hz system was made continuous between New York and Philadelphia in 1931, and was completed southward to Washington in 1935. It was extended to its present status by the electrification of the main line from Paoli to Harrisburg, and from Columbia to Perryville, Md., in 1938.

The electrification covers 656 route-miles (950 km), which includes 3460 km of track equipped with 11 000-volt overhead catenary wires, 1680 km of 132-kV aerial transmission, 17 km of 132-kV underground cable, 960 km of 6600-volt signal power lines, and 67 substations and switching stations supplying power to the overhead contact system.

All power is presently purchased at 13 200 volts, 25 Hz single phase, from four electric utility companies. It is supplied at seven points from 17 generators and frequency changers. It is stepped up to 132 kV at six supply point substations. Railroad-owned substations also contain the transformers and switchgear necessary to control power to and from the 11 000-volt catenary, 132-kV transmission, and 6600-volt signal systems.

There are two basic types of catenary and transmission supporting structures: the cross-catenary, for four tracks; and the bracket arm, for two tracks. Special construction is used for gantry signal bridges. The standard contact is a 4/0, or 300 000-cmil, round, grooved solid-bronze wire; but on mainline tracks, for high-speed service, a 336 400-cmil, grooved, long-lobe solid-bronze wire is employed. The average life of this latter wire is estimated to be more than 40 years.

The entire PRR system is controlled from a central load dispatching office in Philadelphia. The load dispatcher coordinates the operations of railroad power directors in New York, Philadelphia, Baltimore, and Harrisburg, and the four electric utility companies that supply the system. The load dispatcher is kept informed, by means of telemetered analog readout and printout displays, of output in kilowatthours, load transfers, and power demands and power consumption. Each power director also has a model board as a guide to the operation of the electric system in the particular zone over which he has control.

Description of locomotives—past and present. With the exception of the Class DD-1 dc locomotives (Fig. 1), only a few experimental locomotives, such as the Class FF-1, with four 3-phase motors, the Class L5 (freight and passenger), with four single-phase motors, and the L5A dc locomotives (two shown in Fig. 2) were built prior to the 1930s.

The first of a series of ac road locomotives, with ac series motors and flexible gear or spring drives, were built between 1930 and 1933. Included in this group was the Class P5 locomotive, which had a nominal rating of 2800 kW, with a short-time capability of about 4200 kW. Originally designed for passenger service, these 100-tonne engines were regeared for a maximum speed of 110 km/h—adequate for freight service. The last unit of this class was retired in 1965.

The GG-1 locomotive (Fig. 5), the backbone of the railroad's locomotive fleet, was first built in 1935. Weighing 136 tonnes, it has a nominal rating of 3450 kW, and can develop 6350 kW for short periods of time. Each driving axle of both the P5 and GG-1 locomotives was equipped for propulsion with a twin motor, geared to a quill shaft, with flexible members (spiders) engaging the spokes of the driving wheels. Most of the GG-1s are geared for 145-km/h passenger or freight operation.

In 1951, five experimental two-unit electric freight locomotives were placed in service. Each locomotive consisted of two A-type articulated units (control cab at either end) having simplified trucks with small driving wheels (112- to 122-cm diameter), motors geared directly to axles, and dynamic braking. Each unit also had two pantographs and one askarel-filled main transformer with secondary taps, and was geared for 105-km/h service.

Three of these locomotives, each weighing 224 tonnes and with a rating of 3700 kW, were equipped with one ac traction motor per axle. The motors were permanently connected in parallel groups of two. The remaining two

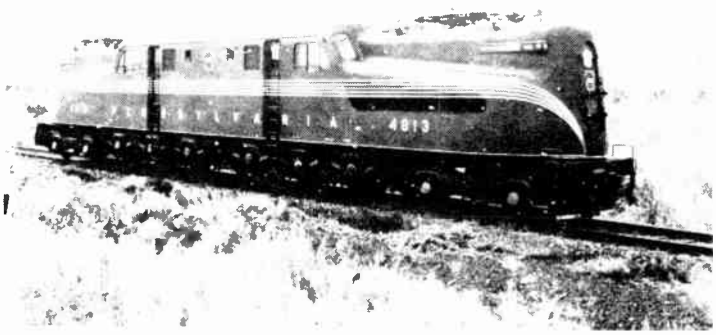
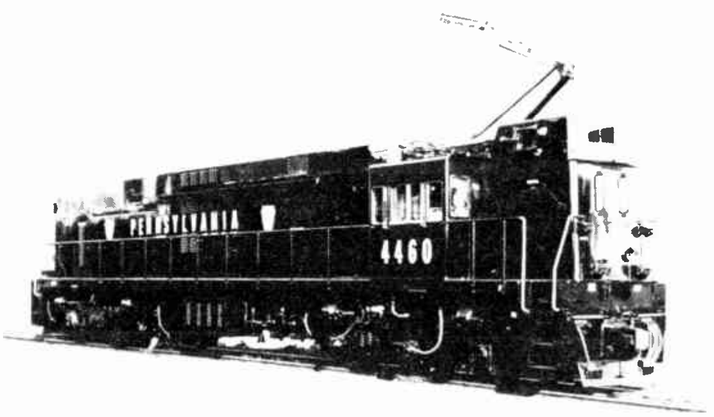


FIGURE 5. One of the PRR's fleet of GG-1 locomotives. These powerful engines, developing up to 6350 kW, can haul a 15-car passenger train at a maximum speed of 145 km/h. The GG-1 type dates back to 1935.

FIGURE 6. The Class E-44 silicon-diode rectifier locomotive unit, the latest type of engine to be placed in PRR service.



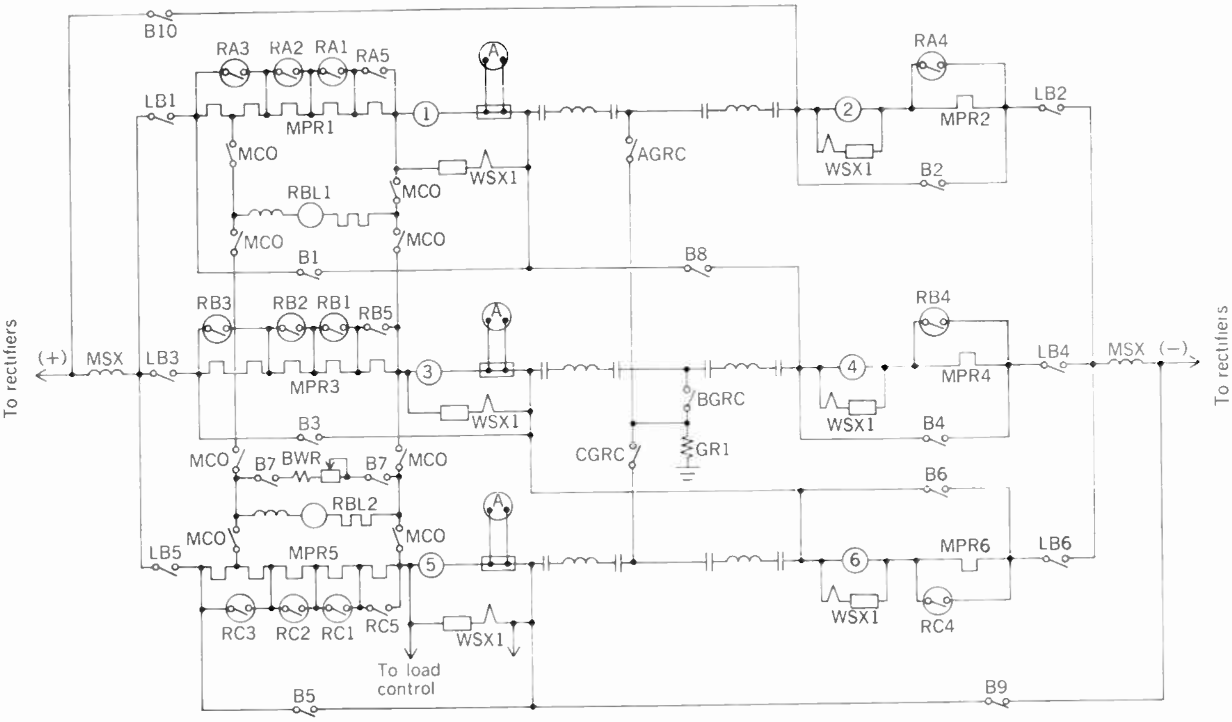


FIGURE 7. Block diagram of propulsion circuit for PRR's Class E-44 locomotives.

locomotives (Classes E2C and E3B) weighed 329 and 344 tonnes, respectively, and were rated at 4500 kW continuously. Each unit had six dc traction motors permanently connected in parallel, with each motor supplied from two ignitron rectifiers across the main transformer secondary. All of these experimental machines were retired after serving the useful purpose of furnishing information for the design of replacement freight locomotives for the retired Class P5s.

These replacements, designated as Class E44 (Fig. 6), were built from 1960 to 1963. Each rectifier locomotive of this class weighs about 175 tonnes and is rated at 3300 kW. The six dc axle-hung traction motors on each of these units are identical to those used on many diesel–electric locomotives; they are permanently connected, two in series, and three series groups in parallel (as shown in the Fig. 7 diagram). Variable-voltage steps for acceleration are provided by transformer secondary tap-changing and resistance control. Dynamic braking is provided by shunting each traction motor armature with the accelerating resistors while all six motor fields are connected in series across the rectifier output.

The original design of the E44 was based on rectifier apparatus of 12 ignitron tubes, because at that time no suitable air-cooled silicon-diode rectifier equipment had been developed to the point at which it would be as reliable as the water-cooled ignitron system. But since it was felt that silicon rectifiers would eliminate the troublesome features of ignitron rectifiers, such as firing circuits and water-cooling and temperature-regulating devices, an intensive effort was made to develop a satisfactory solid-state rectification system. Thus, the 37th locomotive to be built in this series contained a bridge-connected rectifier package (Fig. 8) with 384 cells rated at 250 amperes, 600 volts PRV. This locomotive performed so well that the last five E44 units to be built were also equipped with silicon rectifiers. An additional change was made in the last unit by using silicon diodes rated at 1200 volts PRV, thereby reducing the number of cells in series from 12 to 6, and the total number from 384 to 192.

In addition, 16 other locomotives in this class were converted from ignitron to silicon rectifiers by the end of 1967.

Multiple units: past and present. Until 1958, the PRR multiple-unit cars differed little from the basic model placed in service in 1915. Each motor car of that era has one pantograph and one transformer to collect the 11 000-volt energy from the overhead contact system and convert it to the 850 volts (maximum) suitable for ac series traction motors. Unit switches connected to the transformer secondary taps control motor voltage to maintain uniform acceleration. These cars are equipped with multiple-unit control apparatus and cab signal indicators at both ends. The earlier car models had air-cooled main transformers, but the later models have askarel cooling. One variation of the standard prototype of this series is the 46 semipermanent-coupled motor–trailer unit combinations containing two motors, each rated at 275 kW.

In July 1949, one multiple-unit car was equipped, for experimental purposes, with ignitron rectifier tubes and two 172-kW dc traction motors. This car (no. 4561) operated successfully and was the basis for all future rectifier equipments aboard locomotives and multiple-unit cars, both on the PRR and other roads.

In 1958, the railroad received six 26-meter-long, air-conditioned stainless-steel prototype rectifier multiple-unit cars. These lightweight (41-tonne) cars were built to determine the type of modern equipment that could efficiently replace the existing outmoded fleet of commuter cars dating back to 1915. The prototypes have an acceleration rate of 0.6 m/s^2 and have a top speed of 145 km/h.

The cars are also equipped with roller bearings on lightweight trucks whose bolsters support the car bodies on air springs. Originally, four ignitron tubes on each car furnished direct current to the four traction motors connected two pairs in series parallel, but in 1961, these tubes were replaced by a silicon-rectifier package consisting of 56 diodes on each of two cars.

In 1963, 38 new multiple-unit cars, called "Silverliners," were placed in service on suburban runs in the Philadelphia area. These 26-meter-long cars are the first on the railroad to use Faively pantographs (Fig. 9) and silicon-diode main power rectifiers (each of which consists of three bridge circuits and 24 diodes). The diodes are rated at 600 volts PRV and 250 amperes. The Silverliners also employ a new method of voltage control which is a departure from the conventional use of transformer secondary taps: the bridge circuit, through which rectified power is first supplied to the traction motors, is connected to the transformer secondary by means of two air-cooled ignitron rectifier tubes that use phase-shift control to regulate voltage. These rectifiers are rated at 386 amperes rms, and have a maximum applied rating of 700 volts. The main transformer is rated at 735 kVA, and is askarel-immersed with forced-air cooling.

Each of the four traction motors has a rating of 116 kW at 1700 r/min. The maximum speed of the cars is 137 km/h, and the acceleration rate is 0.9 m/s^2, which is the highest for any of the railroad's suburban cars. There is no dynamic braking feature, however, on the Silverliners, and they are not compatible with mixed equipment operation in trains containing other classes of multiple units.

Finally, in 1967, 20 additional Silverliners, of the same general specifications as their predecessors, were put in service. The further development of modern multiple-unit cars was given a great thrust forward with the enactment, in 1965, of the High-Speed Ground Transportation Research and Development Act. The future prospects resulting from this legislation will be discussed in the second installment of this article.

Before plunging into the historical chronicles of the several other major railway electrification programs in the United States during this century, it might be well at this point to evaluate the original advantages of steam and electricity.

Steam vs. electricity

Long ago, in the days when the steam locomotive was the only competitor to electrification, Baldwin-Westinghouse catalogued the "Advantages of Railroad Electrification" in a company pamphlet[3] of that title. First of all, the steam locomotive was inherently a machine of limited power; that is, its capacity depended primarily upon the amount and working pressure of the steam that could be supplied by its boiler. And the boiler size was necessarily limited by the curve radii and tunnel clearances of the railroad. Electric locomotives, however, are machines of theoretically unlimited inherent capacity because the power plants and transmission lines may be built to such capacity as will supply the amount of power required. Although an electric locomotive is also restricted by the dimensional requirements of standard railroad clearances, its hauling power may be vastly increased by connecting in series any number of locomotive truck units desired, each of which may be equipped with the necessary motive and control apparatus, and the whole controlled as a unit from the cab at either end of the locomotive assembly. Articulations between the truck units ensure that the locomotive will negotiate all curves to operate as a single traction vehicle.

Other salient advantages cited for electric locomotives—in addition to the elimination of smoke, noise, and noxious gases—were

1. *Greater working range and factor of availability.* The electric locomotive can travel up to 4800 km without the need for more than minor inspection, whereas the steam locomotive's range was only about 400 km before layup in the engine house for minor repairs, inspection, and cleaning.

2. *Motor equipment modules can be added to the locomotive unit to attain any practicable speed desired on a specific train under given conditions.* For example, steam locomotive operation on mountain divisions was limited to double-header and "helper" combinations for long freight hauls on grades. This was accomplished at greatly reduced speeds and unequally applied torque for tractive power. By adding power units in electric locomotion, however, synchronism is achieved and a smooth application of equalized torque for drawbar is assured; and, in most cases, the rear-end helper engine can be eliminated.

3. *Electric operation is more reliable than steam.* Steam locomotives were subject to great variations in their power and efficiency with changes in weather conditions, the quality of the fossil fuel, and their state of repair. Steam locomotives would often freeze up in the winter months and damage would result from the bursting of steam lines and the cracking of fire tubes. The electric locomotive, on the other hand, is unaffected by cold-weather conditions insofar as motor efficiency is concerned.

4. *Engine house expenses, capital investment, and operating costs are greatly reduced.* The double-end cab control stations on electric locomotives permits them to run equally well in either direction, and eliminates the turntables necessary for steam locomotive operation. Special maintenance personnel for steam equipment are not required, and small crews only are required for inspections and light repairs.

5. *The descent on heavy grades (two percent and more) with steam-drawn trains was by means of air brakes; with electric operation, these grades may be negotiated by means of dynamic, or regenerative, braking without the use of the service brakes.* Dynamic braking is a system of braking in which the traction motor is converted into a generator that is driven by the kinetic energy of the locomotive on a downgrade, thereby exerting a retarding force. Essentially then, the motors operate in reverse to feed back electric energy to the conductor. In steam locomotive operation, the dissipation of the train's kinetic energy into the brake shoes resulted in excessive wear and tear on mechanical parts. Regenerative electric braking eliminates this problem. Also, a margin of safety is provided, since full air pres-

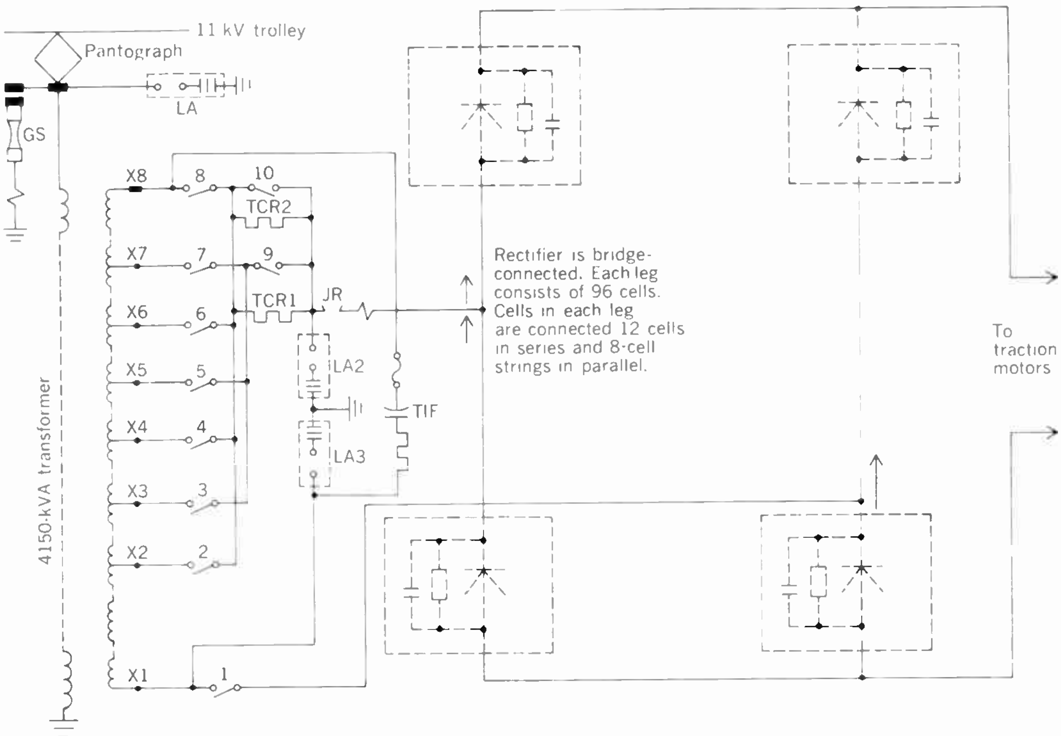
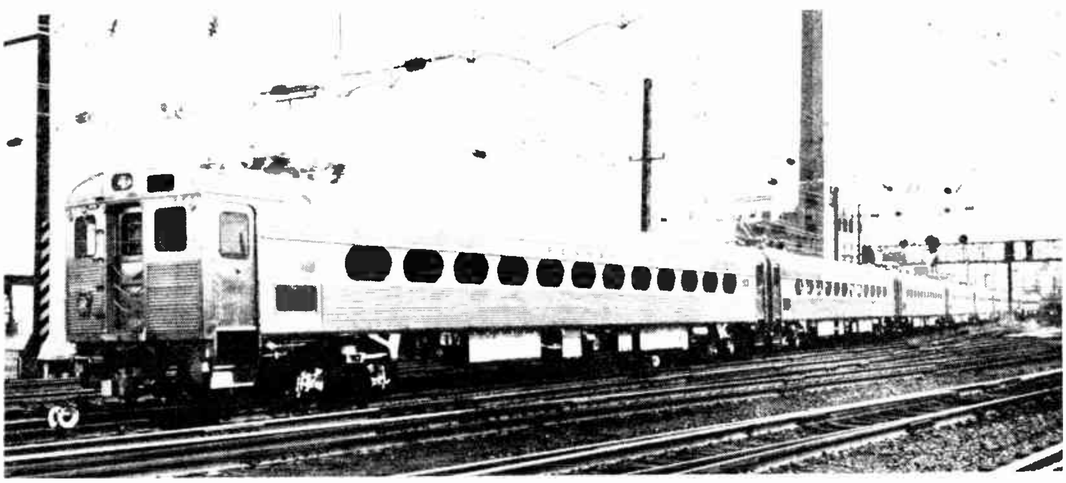


FIGURE 8. Diagram of power supply circuit (Class E-44 locomotives) with silicon-diode rectifiers.

FIGURE 9. The new "Silverliner" multiple-unit cars, in service on PRR suburban routes since 1963.



sure is maintained in reservoirs in case the overspeed breakers trip out the dynamic system.

6. *A higher rate of acceleration is possible with electric operation because of its inherent short-time overload capacity*. Further, the controlling devices of electric locomotives permit a uniform rate of acceleration in hauling heavy freight trains. This is important in reducing the delays caused by coupling and linkage breakage when removing the slack from trains.

7. *The prevention of fire produced by steam locomotive sparks is a distinct advantage of electric operation in heavily wooded sections of the country*.

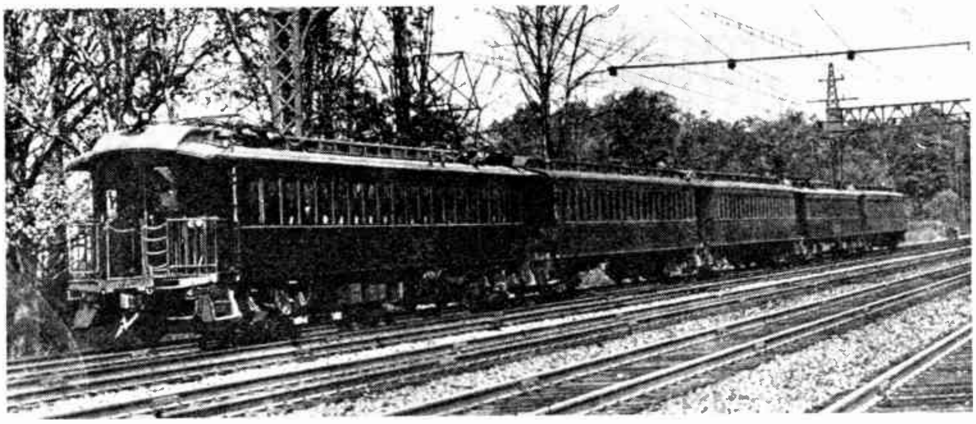
The steam locomotive is gone now—finally phased out in the United States and Canada in 1959. But another major competitor to electrification was the advent of the diesel electric locomotive in the 1940's. Its impact on railroads, and the economic edge it affords, will be discussed in the next installment.

Early electrification of the NYNH&H

In June 1895, an 11-km stretch of double-track line of the New York, New Haven & Hartford Railroad Company between Nantasket Junction and Pemberton (Mass.) was equipped with experimental overhead trolley wires.[4] The energy for this pioneer electrification project was generated in a powerhouse whose nominal capacity was 138 kW. The energy was distributed at 600–700 volts by means of a lightweight copper contact wire,

FIGURE 10. The GE-built 86-tonne electric locomotive on its official test run, November 12, 1904. This was the prototype of a series of steeple-cab engines specially built for the New York Central Railroad. A few of these early locomotives are still in yard service.

FIGURE 11. A New Haven Railroad multiple-unit train of the old open-vestibule type. Placed in service in 1909, these cars were phased out in the late 1950s.



which was rolled specially for the system by the J. E. Roebling Company, the famous builders of the Brooklyn Bridge. The wire hung on brackets supported by wood poles set in concrete. Other than the poles themselves, there was no insulation for the live wire.

The original rolling stock consisted of ten motor cars and a number of trailers. The average train length was four or five cars, with each car seating about 80 passengers.

The success of this initial venture in heavy electric traction was so great that a new zone was planned for the following year to extend the line 5.5 km to East Weymouth. And, in December 1896, electrified third-rail systems were constructed in Connecticut from Hartford, through New Britain, to Berlin—for a total distance of about 20 km. In the following year, this project was extended 15 km to Bristol.

Although the third rail overcame many of the operating problems that resulted from the trolley poles and wires, the hazard to life and limb was great. The third rail, rolled in the form of a flattened, inverted "V," was mounted—entirely exposed—atop wooden blocks that were carried by the crossties midway between the running rails. It requires little imagination to visualize what fate befell unwary human or animal trespassers that blundered into the 600-volt contact rail. Thus, when the Stamford–New Canaan single-track line was built, the railroad reverted to the overhead system—which it employs to the present day—east of the Woodlawn (Bronx) junction with the New York Central tracks.

Electricity comes to the New York Central

Because block signals were obscured by smoke and steam from a passing train, a disastrous wreck occurred in the New York Central Railroad's Park Avenue tunnel approach to Grand Central Terminal in 1902. Subsequently, the New York State Legislature ordered the abandonment of all steam operations in the tunnel by July 1, 1908.

The General Electric Company had proposed the electrification of the tunnel back in 1899, but the railroad showed no interest in the scheme—until the tunnel accident. Then, the New York Central officials examined electrification proposals from both GE and Westinghouse. A prototype dc third-rail pickup locomotive, no. 6000, was completed by GE during the summer of 1904, and it was road-tested alongside the Central's main line at Schenectady. The live demonstration of the 86-tonne, steeple-cab engine (Fig. 10) on November 12, 1904, so impressed the Central's management that it accepted the GE third-rail system without requesting a comparable demonstration of the overhead system proposed by Westinghouse!

For the next ten years, the electrification program proceeded apace in the following sequential steps to complete the present-day electrified territory of the New

York Central in the New York metropolitan area:

1. *Initial zone operation.* This comprised the electrification of the old Grand Central Yard and four tracks on the Harlem Division, from 57th Street (Manhattan) to Mt. Vernon (Westchester); and two to four tracks on the Hudson Division, from the Mott Haven Yards to High Bridge (Bronx). This project, totaling 124 km of third-rail installation, was completed in 1907.

2. *Extension to Yonkers.* This extension included four tracks from High Bridge to Marble Hill, and two tracks north to Yonkers—for a total system third-rail length of about 160 km. It was completed in April 1908.

3. *Extension to North White Plains.* This phase included the erection of third rail on two tracks from Mt. Vernon to the far end of the North White Plains yard. This work, completed in March 1910, increased the electrified length to 220 km.

4. *Extension to Hastings and Tarrytown.* This phase, completed in two steps, by the end of 1911, brought the electrification of all four tracks on the Hudson northward a distance of 16 km, increasing the system third-rail length to about 300 km.

5. *Extension to Croton-on-Hudson.* This final phase of the Hudson electrification to its northernmost terminus was finished in March 1913. Total system: 380 km.

6. *Electrification of Grand Central Terminal and the Harmon Yards.* The present Grand Central Terminal was completed in 1914. Its underground network on two levels contains more than 60 platform tracks and a huge yard layup area that extends north to 55th Street. This undertaking, plus the electrification of the Harmon-on-Hudson yards, was completed in 1915, and brought the system's total electrified trackage to its present 500-km length. (In railroad parlance, the New York Central's electrified territory from Grand Central Terminal extends 69 "route-miles." For the definition of this and other railroad terms, see the Appendix.)

Multiple-unit service inaugurated in 1905, was extended throughout the electrical territory in 1914, with a fleet of 200 motor-car units, some of which are still in local service on the Hudson and Harlem Divisions from Grand Central to Yonkers and Mt. Vernon. In a three-stage rolling-stock modernization program, some 200 new multiple-unit cars were placed in service in the period between 1951 and 1965.

The original steeple-cab locomotives, built between 1905 and 1908 (designated as Type S-2), were used in express-train passenger and freight service on both divisions until 1913, when they were largely superseded by two more powerful classes of box-cab freight and passenger locomotives that were built by GE and American Locomotive (Alco-GE). Although the old S-2s were retired from scheduled road service about 20 years ago, there are still a few of these venerable engines in service as switchers in the Grand Central area and the Croton and North White Plains yards.

Joint electrification: New Haven and New York Central

Some electrical engineers contend that more than 650 volts cannot be carried safely in a third rail; thus, the overhead catenary is the only solution for higher voltages. The New Haven Railroad (NYNH&H), which shares a common right of way with the New York Central from Grand Central Terminal to Woodlawn, chose to use single-phase ac, 11 000-volt energy for its overhead lines—to be constructed in two phases—between Woodlawn and Stamford, Conn. Since the New York Central had installed 600-volt third rails, with underrunning contacts, as standard equipment in its electrified territory (and these rails might be located at either side of the track), the New Haven was confronted by some knotty problems in the design of its electric locomotives and multiple units (Fig. 11).

Electric service on the New Haven was inaugurated between Grand Central Terminal and New Rochelle—a distance of 27 km—in July 1907. All New Haven locomotives and multiple-unit cars were equipped with a dual collection system: pantographs for the overhead ac line, and compatible third-rail shoes for the New York Central's electrified track. Local suburban service was extended to Stamford in October of that year, and full electric passenger service between New York and Stamford was established on July 1, 1908. This service was maintained by a group of 35 Baldwin-Westinghouse locomotives, which were the most complex and sophisticated traction engines of their time.

The final phases of the New Haven's present electrification occurred in 1914, when the line was extended eastward to New Haven, northward to Danbury, and across the Hell Gate Bridge to connect with the Pennsylvania Railroad in Long Island City (Sunnyside).

The Milwaukee Road: longest electrified east–west line

The Chicago, Milwaukee, St. Paul and Pacific Railroad Company (called the Milwaukee Road) operates freight and passenger service across the northern tier of the United States from Chicago to the Pacific Northwest, with western terminals in Seattle and Tacoma, Wash. Slashing through the Rocky Mountains and the Cascade Range in Montana, Idaho, and Washington, the railway was in a strategic region to make use of available hydro power in its electrification program. By 1913, the Montana Power Company had hydro plants, whose output was more than 70 000 kW. The theory of many plants, situated on several watersheds and all interconnected by means of an extensive transmission system, had proved the dependability of hydro power. The 5900-kW output of the company's standby steam-electric plants were used only at times of peak power demand.

In March 1914, the Milwaukee Road's electrification department was established, and the Montana Power Company obtained permission from the Secretary of the Interior to construct power distribution facilities between Harlowton, Mont. and Avery, Idaho, a distance of some 700 km. By December 1915, the electrification of a 180-km stretch between Deer Lodge and Three Forks, Mont., was completed.

Full electrified service between Harlowton and Avery (Missoula and Rocky Mountain Divisions) began early in 1917. This line was so successful that the railroad undertook the electrification of the Coast Division (Othello to Tacoma, Wash.), a distance of 330 km, and completed this project in 1920 (see Fig. 12 map).

Without question, the electrification of the Milwaukee Road was the most spectacular (and best advertised) project of its type in the pre-World War I world.

The original traction units. The initial motive power units, designed for the 3000-volt dc overhead system, were built by Alco-GE. The first of these, locomotive no.

10200 (Fig. 13), was delivered on September 25, 1915, only ten months after the order was placed. This 34-meter-long, 260-tonne, engine contained eight GE motors rated at a total of 3075 KW. It was designed to haul a 2500-tonne train up a one percent grade at a speed of 26 km/h. And the only restriction on the size of this giant was the strength limitation of the freight car draft gear of the day—which, as we shall soon see, could present a problem.

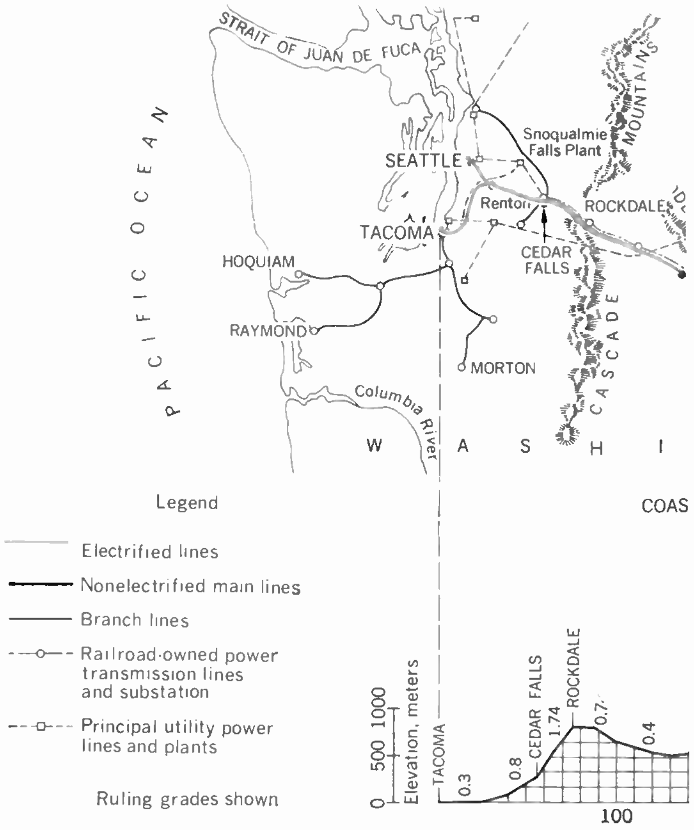
Locomotive 10200 was quickly followed by 41 similar units to serve the Rocky Mountain Division from Three Forks to Harlowton. The winter of 1915–1916 witnessed temperatures down to −40° C in the mountains. A graphic account of how well the electrics performed in the bitter cold is best told in the words of a Milwaukee Road division superintendent:

"At a time when the thermometer was at −40°, two freight trains, having three steam locomotives and 75 cars, were standing on the main track east of Three Forks, Mont., with the engines dead because of the freeze, and passenger trains were due in both directions. The superintendent was anxious to clear the main line, but had no steam engines available. An electric freight locomotive was standing on a side track. The line was not in electric operation east of Three Forks, but for a distance of nine miles [14.5 km] the trolley was energized. The superintendent asked an engineer if the electric locomotive could clear the track. The engineer said he could; so he and the super boarded the electric, raised the pantograph, and the locomotive was instantly ready for service. In five minutes' time, the electric moved out to the main track, and without the slightest difficulty, the two trains were coupled up. The 75 cars and three steam engines were pulled into the siding at Three Forks by the big electric. The main track was cleared, and there was no delay to the passenger trains."

This salient advantage of electric over steam in cold weather operation was well illustrated, but there were also some unpredictable mishaps in the conversion from steam to electric operation. Insley J. Brain, Jr., a chronicler of the history of The Milwaukee Road,[5] tells of one of these incidents of 1916 in an unexpected low-key narrative: ". . . Meanwhile the train crews, especially engineers, were 'getting the hang' of this new-fangled power. Operation of the electrics was simple . . . heated cabs, ammeter to tell how hard the engine was pulling, regenerative brakes, good visibility, increased speed on grades . . . were welcome improvements.

"By April 1916 . . . freight train operating technique was pretty well standardized. The electric would couple to the train, and the brakes [would be] pumped off. Now, on sanded, dry rail, one of these fine new locomotives exerts 120 000 pounds [55 000 kg] drawbar pull, so starting should be real easy. Just release the brakes, yank the controller back three or four points, and . . . say, have you ever seen a 36-foot [11 meter] 1900-vintage wood underframe boxcar in two 18-foot sections?" So much for the limits on drawbar pull and snapping the slack out of a stopped train too fast!

Steam locomotives were used for many years as "helpers" (rear-end pushers) to assist electric-hauled long freights up the mountain grades. Brain describes an incident, occurring in the 1920s, that sounds like the scenario for a silent movie thriller of that era (note: italicized terms will be explained in the Appendix)—



"Shortly after electric operation commenced on the Cascade Division, 'all hell broke loose' one morning, and the boys learned that there are limits to all good things—even regenerative braking. Seems a train of 59 loaded cars with a *juice jack* on the *point* and a *Mallet helper* on the rear crested the summit of the Saddle Mountains and started down the long (18 miles, 2.2 percent) grade to Beverly.

"As usual, no air was applied, and the minimum speed of 15 mi/h [24 km/h] for regeneration allowed to pass. At about 30 mi/h [48 km/h], the engineer tried to cut in the regeneration—and promptly blew his breakers. Tried again—same result. Tried *service braking*—and went a little faster. Tried *big hole*—and speeded up to about 35 mi/h [56 km/h]. Between the independent brakes of the heavy Mallet on the rear and the electric on the front, and some hand brakes set up before they started down, nothing came *unglued* until Doris, about 11 miles [18 km] downgrade. There, the Mallet's *tender* jumped the track on a bad switch, shaking her loose from the train.

"Sans anchor, said train rolled on around 10-degree curves at a merry 50 mi/h [80 km/h]. Shortly, 28 carloads of shingles came unglued and hit the ditch, breaking the 100 000-volt transmission line, and burned up. A couple of miles more and 13 additional cars scattered all over the landscape. Finally, the juice jack shook the last of the cars, which promptly burned, and continued on for some distance before stopping.

"What with 59 cars scattered about, a Mallet on the ground, and a long flat spot on every wheel of the electric, it was decided that, perhaps, the train should be

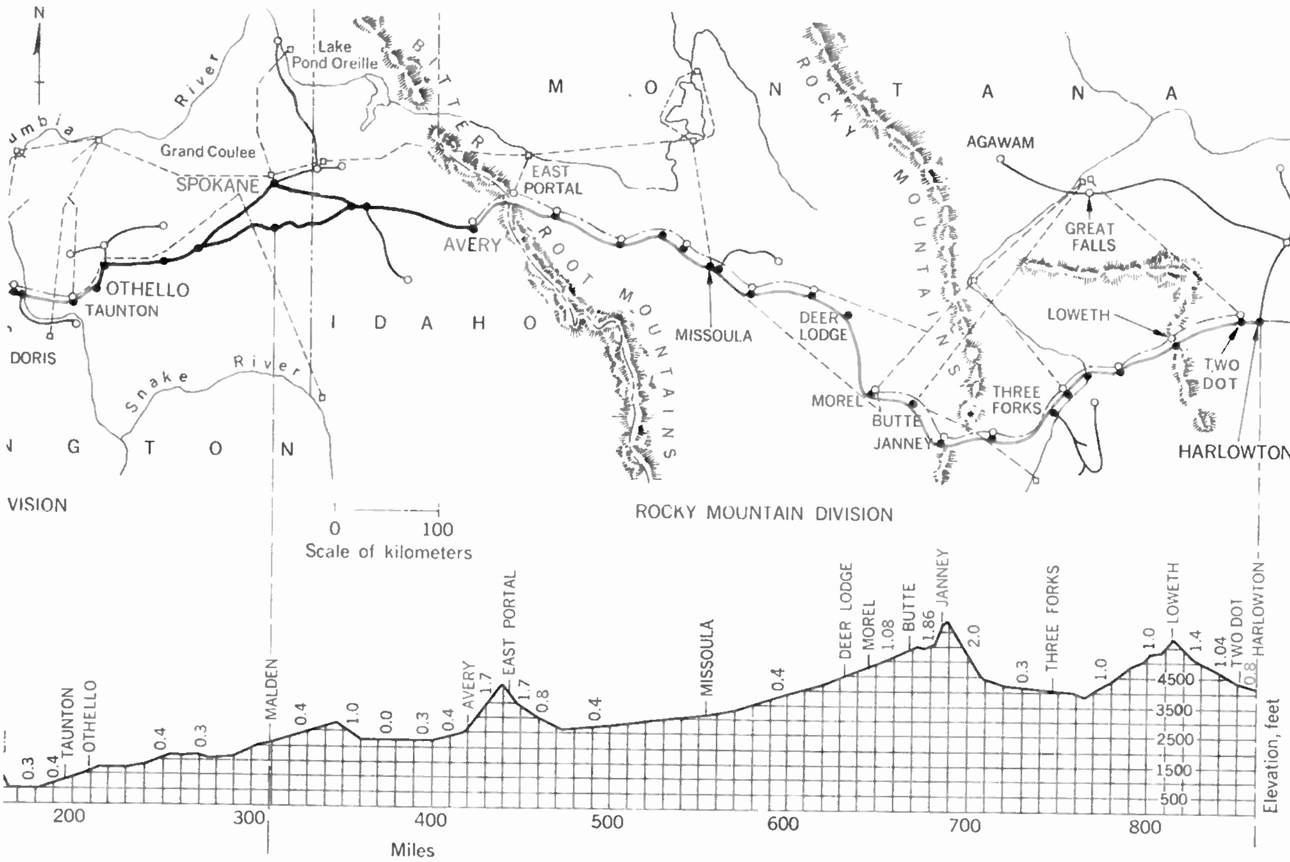


FIGURE 12. Condensed map and profile of electrified and nonelectrified divisions of the Milwaukee Road in the states of Washington, Idaho, and Montana. Note: the numerals along the right-of-way profile indicate the various grade percentages en route.

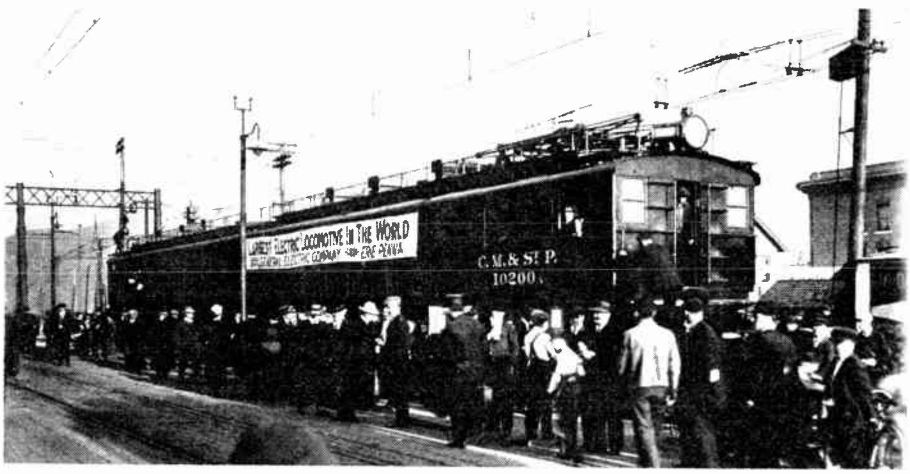


FIGURE 13. The first electric locomotive for the Milwaukee Road. This 1915 photo shows no. 10200 (billed as the world's largest electric) on display at Butte, Mont., prior to its placement in regular service.

under control of air brakes before gaining enough speed for regeneration!"

The later locomotives. In 1920, Baldwin–Westinghouse supplied ten "box cab" locomotives for passenger service on the Rocky Mountain Division. These engines, similar to those built for the New Haven Railroad, had regenerative braking, and weighed 280 tonnes. Rated at 3150 kW, and a maximum safe speed of 105 km/h, they had six axles, each of which was driven by a two-armature motor, with each armature designed for 750 volts. The motors were entirely truck-frame-supported, and each armature was geared to a single quill-mounted drive gear. The quill shafts surrounded the axles and were carried by the truck frames. They, in turn, drove the wheels by means of a "spider" sprung to the wheel spokes. The chief advantage of a quill drive is that the unsprung weight is limited to wheels, axles, and bearings; all motor and gear weight is sprung. Also, slippage shocks are dampened by springs before they reach the gear teeth. These huge locomotives remained in service until about 1954, when they were scrapped because of a decline in passenger service.

Probably the best known of the Milwaukee Road's traction power equipment is the "bi-polar" locomotives, originally built by Alco-GE in 1919–1920. These 23-meter-long, 240-tonne, three-section steeple-cab engines (Fig. 14) were primarily intended for the passenger service on the Cascade electrification between Othello and

Tacoma. The bi-polars achieved fame not only for hauling the Milwaukee Road's crack "Olympian-Hiawatha" express, but also as a prototype model for Lionel Lines' toy electric train sets!

Twelve gearless motors on 12 axles, wound for 1000-volt direct current, are operated in groups of three, four, or six—or all—in series as operating conditions require. Field taps and resistances provide additional control. Developing about 4500 kW, the successive power trucks are coupled in such a way as to dampen any lateral oscillations caused by a rough roadbed. Thus, smooth-riding qualities are assured at speeds up to 112 km/h. Like the other road engines, the bi-polars feature regenerative braking; four of the motors supply the necessary exciter current, thereby reducing motor-generator requirements during regeneration.

Since 1960, these fine locomotives have been laid up because of the railroad company's present policy of running diesel-electric locomotives in through passenger service.

"Little Joes" and "Jeeps." At the end of World War II, there were persistent rumors that the Milwaukee Road would abandon its electrified divisions in favor of diesel power. The existing electric equipment was aging and the long catenaries were in need of replacement and repair. Nevertheless, the company purchased 12 new GE locomotives, originally intended for foreign railroads. Dubbed the "Little Joes," these massive, 266-tonne engines are rated at 3800 kW, with a tractive effort of 50 000 kg. This class of locomotive can be effectively operated in tandem as a multiple unit. And tractive power can be increased to about 9500 kW by the head-end combination of two "Joes" and a "Jeep"—a diesel-electric helper engine called the Electro-Motive GP-9—to permit a 5300-tonne train to move eastbound on the steepest grade without rear-end helpers. The diesel control system for this multiple-unit combination is simple: a miniaturized diesel controller is mounted atop the electric controller of the lead locomotive by means of a readily demountable arm. Inside the electric's controller, microswitches, tripped by the Joe's reverser, manage the reversing of the diesel. In front of the motorman is a small diesel control panel mounted just to the right of the four instruments that apply to the electric operation (two ammeters, a speedometer, and the line-voltage meter). The diesel controls include switches for "control and fuel pump," "engine run and controller," "generator field," "headlight," and "engine stop."

Under normal electric operation, the arm between the two controllers is disconnected and the diesel control switches are shut off. But when heavy grades make the use of the diesel helper necessary, the arm is connected, switches are turned on, and the 1100-kW Jeep is "cut in." Although it has been necessary to disconnect the controller arm whenever regenerative braking is used, a modification to the system now permits the electric's regeneration to be assisted by the diesel's dynamic braking.

Power plants, transmission, and distribution

The Montana Power Company, under a long-term contractual agreement, built the necessary facilities to generate and distribute power to the railroad's Missoula and Rocky Mountain Divisions (Avery to Harlowton). In 1916, the utility had a generating capacity of about 160 000 kW in this area, a large portion of which was used to supply the cities of Butte and Helena. Of this available generation, 60 000 kW was produced by the then new Great Falls of the Missouri River hydro plant. A convenient bend of the track routing northeast of Butte placed the railroad within 190 km of this power station all the way from Harlowton to Butte. Thus, the construction of a single transmission line (100 kV) to the railroad just west of Harlowton, together with the extensions of available transmission lines near Butte, supplied power to about two thirds of the eastern electrification. Supplying power to the western end of the Missoula Division (about 320 km west of Butte) was not so simple, however, since there was no large commercial load center nearby. Hence, a 30 000-kW hydro plant was built at Thompson Falls on the Clark Fork of the Columbia River. A short transmission line to East Portal (on the Idaho–Montana border) supplied the west end of the electrification.

Between Othello and Tacoma–Seattle (Coast Division), power is supplied by the Washington Water Power Company, and the Puget Sound Light and Power Company. Most of the power on this section is obtained from the Snoqualmie Falls hydro plant, which also supplies commercial power to the Seattle area. And the Long Lake dam hydro project on the Spokane River furnishes power to the railroad's Taunton substation via a 180-km-long transmission line.

Although the power companies did not have any major problems in constructing their share of the transmission lines, it was necessary for the railroad to build more than a thousand kilometers of 100-kV ac lines to deliver power to isolated substations. Twenty-two of these substations are spaced an average of 50 km apart on all of the electrified divisions.

From the transmission line, the electric energy passes through the choke coils, disconnect switch, and oil-cooled circuit breaker to each of the two or three transformers in a typical substation, where the 100-kV, 3-phase, 60-Hz alternating current is stepped down to 2300 volts. At each substation, two disconnect switches are installed in the main transmission line—one on each side of the transformer connection. Thus, in case of a line break, the affected substation can be isolated from the others. It is interesting to note that the railroad's transmission line between Taunton and Cedar Falls (Wash.) was for many years the only interconnection between the Washington Water Power Company and the Puget Sound Light and Power Company. Therefore, in the event of a section outage, the substation operator had to get the two utilities in phase with each other before reclosing the line.

In recent times, ten of the 14 Rocky Mountain Division substations have been set up for remote control. One Cascade division facility is remotely controlled and a second substation is fully automatic.

The railroad's overhead line is a "flat" catenary, with 1.25-cm-diameter galvanized steel cable messenger and loop supports alternately holding two *4/0* copper contact wires. Each of these dual contact wires is supported at 5-meter intervals. The return system is via the rails (*4/0* wire, welded at rail joints), with a *4/0* feeder along most of the main line. This return feeder is carried at the top of the catenary support poles and also serves as a lightning arrester.

FIGURE 14. One of the famour "bi-polar" locomotives built for the Milwaukee Road by Alco-GE in 1919–1920.

Electrification of other railway systems

The Long Island Rail Road. The LIRR inaugurated its first electrified line, a 650-volt dc third-rail system, on July 28, 1905, between Flatbush Avenue (Brooklyn) and Rockaway Park. An 80-tonne steeple-cab locomotive, capable of exerting a 27 000-kg drawbar pull, hauled the first train. By the end of that year, the electrified line was extended, in two stages, as far as Valley Stream.

The first multiple-unit cars—134 in all—designed by the famous electrical engineer George Gibbs (a long-time associate of Westinghouse) were placed in service in 1908. Electrification of the Hempstead Branch of the railroad was also completed in 1908, and the system was electrified from Pennsylvania Station in Manhattan to Jamaica (Queens) in 1910, following the completion of four single-track tubes under the East River. From that date to 1925, electrification was extended to include the main line to Mineola; the South Shore line to Babylon; and the West Hempstead, Long Beach, Far Rockaway, and Port Washington branches. Today, the system's rolling stock numbers 829 multiple-unit cars (of several vintages), 347 of which are equipped with speed controllers. This line, the most heavily traveled U.S. suburban system, carries 260 000 riders daily on weekdays.

The Norfolk & Western and the Virginian Railways. The N&W has the distinction of being the first U.S. rail line to apply electric locomotives (1915) to heavy freight service. Because of the advantages in power distribution to heavy trains, the railway selected 11 000-volt, single-phase, 25-Hz overhead power lines. In handling coal trains, the starting conditions were very severe—particularly on grades—and design specifications stipulated that the Baldwin–Westinghouse locomotives should be able to exert full tractive effort at standstill for five minutes. Although this specification was found to be excessive, it led to the choice of polyphase induction motors taking power from the single-phase line through a transformer and phase converter. The tractive effort in starting the 245-tonne, two-unit, 2500-kW locomotives was regulated by liquid rheostats in the traction motor secondary circuits.

On the N&W electrification, each electric locomotive

I. Extent of electrification of principal railway systems in the U.S.

Original Name of Railroad	Present Name	Route-Miles	Route-Kilometers	Present Status
Pennsylvania	Penn Central	656	1050	Full service
Chicago, Milwaukee, St. Paul & Pacific (Milwaukee Road)		670	1100	Limited service
New York Central	Penn Central	69	110	Full service
New York, New Haven & Hartford (New Haven)		106	170	Full service
Norfolk & Western		76	120	Abandoned
Virginian	(Now part of N&W system)	134	214	Abandoned
Great Northern		72	115	Limited service
Long Island		150	240	Full service
Delaware, Lackawanna & Western	Erie-Lackawanna	80	125	Full service

performed the work formerly accomplished by three steam Mallet locomotives; hence, the total number of electrics required was about one third of the number of Mallets that were retired.

In 1925, the Virginian Railway (primarily a coal-hauling line from the mines of western Virginia and West Virginia) inaugurated electric operation with a single-phase overhead system and split-phase motive power units similar to the N&W engines. The requirements of the Virginian's mountain division, however, were so much more demanding than those of the N&W that each locomotive consisted of three motive power units, totaling 5300 kW. And provision was made for operating four units—if necessary—in multiple-unit service. The Virginian electrification included two long grades: one of 18 km, and the other 11 km in length. Thus, the Virginian system accrued additional benefits from regenerative braking. The line was equipped to handle 22 000 volts on the trolley, if desired.

Unfortunately, the competition and economic advantages of diesel locomotion ultimately persuaded both railways (now combined into one system) to abandon their electrification in the late 1950s (N&W), and in 1962 (Virginian).

Delaware, Lackawanna & Western. In the 1920s, under steam operation, the DL&W (now Erie-Lackawanna) passenger terminal and train yard in Hoboken, N.J., were greatly congested by the large number of steam switchers and road locomotives necessary in making up and clearing trains.[6] The terminal handled a large volume of suburban passenger traffic, with very heavy peak loads morning and evening. Therefore, in 1928, the railroad decided to electrify the important suburban service on the main line to Dover, via Morristown; the Montclair Branch, which runs from Roseville Avenue, Newark, to Montclair; and the Passaic and Delaware Branch, which runs from Summit to Gladstone.

Multiple-unit equipment was selected for this service, because it would provide more rapid acceleration at stations, more uniform speeds over the rolling grades in the electrified zone, and more flexible and economical off-peak operation, and would reduce the switching movements required by electric locomotives in train makeup at the crowded Hoboken Terminal.

Comparisons of plans for performing the needed service indicated that a 3000-volt dc overhead catenary would have the advantage over ac in initial capital investment and operating costs, and in the operational characteristics for equal weight of motor equipment. The advent of individual-unit, large-capacity 3000-volt mercury-arc rectifiers improved the operating efficiency of substations and reduced initial capital investment.

The rolling stock for the Lackawanna's 250 km of electrified track consisted of 141 motorcars and 141 trailer cars (coupled as semipermanent two-car units). The electrified service was inaugurated in 1931. From that time to the present day, there has been little modification or change either in the original catenary installation or the company's multiple-unit rolling stock.

Great Northern, and others. When the Great Northern Railway completed its new Cascade Tunnel in 1928, it adopted single-phase 11 000-volt ac at 25 Hz. In January 1929, one of a fleet of Baldwin–Westinghouse electrics pulled the first train through this tunnel to begin the 120-km service between Skykomish and Wenatchee, Wash.

The Detroit, Toledo & Ironton electrified 44 km of track in the same year, and the Reading Company installed electric operation on most of its suburban service out of Philadelphia between 1930 and 1931.

Table I lists the extent of the electrified zones of the principal systems in the United States.

The four types of electrification

In summarizing the great electrification projects in the United States, we may say that they were undertaken to solve four basic operating problems. Initially, electrification was applied to—

Terminal tunnels and trunk-line tunnels. As previously noted, the significant terminal electrifications include the Park Avenue tunnel of the New York Central and New Haven Railroads leading to Grand Central Terminal, and the Pennsylvania Railroad and Long Island Rail Road tubes under the Hudson and East Rivers. The reasons for the electrification of both classes of tunnel were simply safety, and the elimination of smoke, soot, and noise.

The notable trunk-line bores are:

St. Clair Tube (under the Detroit River) of the Grand Trunk Railroad between Windsor, Ont., and Detroit, Mich. In 1893 and in 1903, gas asphyxiation from steam locomotive fumes claimed the lives of a total of five trainmen. The 11 000-volt, single-phase 25-Hz overhead line was completed in 1908, together with the necessary powerhouse and line equipment. Six Baldwin–Westinghouse 60-tonne electric locomotives were used in the initial service; two of these, when operated double-header, could haul a 1000-tonne train up the 2 percent grade at 16 km/h.

Hoosac Tunnel of the Boston & Maine Railroad. This longest railroad tunnel in the United States (10 km) was electrified in 1911, by a single-phase 11 000-volt ac system. The B-W locomotives, with series motors, were of the articulated type, with one motor quill-geared to each driving axle. In starting from the yard

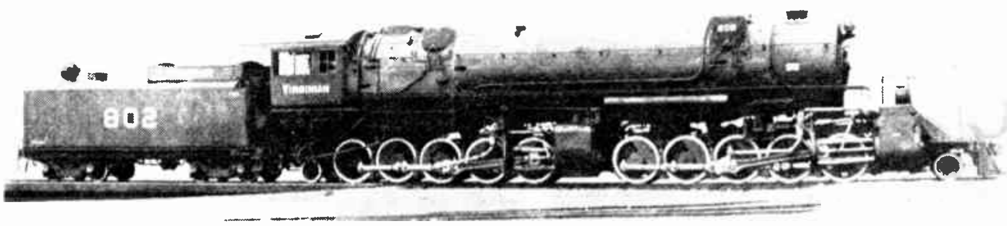


FIGURE 15. A 2-10-10-2 Mallet pusher locomotive of the type formerly used on the Virginian Railway.

outside the tunnel, a steam locomotive helper was used at the rear of the train, but it was pulled through the bore (by the electric) with its throttle closed. This electrification was successful for many years until the diesel locomotive superseded it.

Cascade Tunnel of the Great Northern Railway (described in the previous section).

The second area indicating the need for conversion to electric operation was—

Passenger terminal and suburban service. Railroad terminals in large cities with peak commuter loads were attractive prospects for electrification to relieve the passenger congestion. In steam operation at stub-end terminal tracks, additional locomotives were required for switching trains in the station. For example, in order to release the road locomotive of a recently arrived train, a rear-end switcher must haul this train out of the stub-end track. With electric suburban operation, each car is self-propelled and may be made up as multiple-unit trains of variable length as required, with controller cabs at either end for two-way operation. The quick acceleration feature of the multiple-unit trains improved the speed and service to many commuter lines.

The third problem area solved by electrification was—

Through trunk-line service. In long-distance passenger express runs, the steam locomotives had to be changed after running about 400 km. And there was the additional annoyance to passengers of smoke fumes, soot, and grime. With electric locomotive operation, the same engine could haul the train from terminal to terminal—regardless of whether this distance was 100 or 1000 km, and the cleanliness of the electrified line added greatly to the comfort of passengers.

The final area for service improvement was—

Electrification of heavy grade sections. As we have seen, in the electrification of the Milwaukee Road, N & W, and the Virginian, the increased efficiency, speed, and tractive power of the electric locomotives in hauling heavy freight trains over grades of 2 percent or more resulted in widespread economies in operation, overhead, and maintenance for these railroads.

Green over green—'highballing' to chapter II

In the next installment we shall discuss—among other things—color and position signals, automatic train stops, and wayside safety devices, as well as the prospects of electrification for the future. In case the reader is unfamiliar with the railroad jargon of the subtitle, "green over green" indicates a clear track for the next two block signals, and "highballing" indicates running at near to maximum speed over such a clear stretch. To bring this installment to a full stop, the writer will close—as he began—with an appropriate verse from "The Wreck of Old 97" that contains an implicit plea for regenerative braking:

It's a long rough road from Lynchburg to Danville:
On the line there's a three-mile grade.
It was on this grade that he lost his air brake;
You should ha' seen old 97 roll!

Appendix

The following glossary of railroad terms may be of assistance to the reader.

1. *Articulation, or articulated unit*—a train whose cars are permanently or semipermanently joined at a flexible coupling or draft gear to permit operation over all standard track curves.

2. *Big hole*—this refers to an emergency application of a train's service air-brake system, in which the brake valve opens a large orifice for a rapid discharge of the train line and application of the brakes.

3. *Double-header*—the use of two steam or electric locomotives in tandem at the head end of a passenger or freight train to provide extra tractive power on mountain division grades.

4. *Helper*—a rear-end "pusher" locomotive used to assist heavy trains up maximum grades.

5. *Juice jack*—a term applied to the early electric locomotives by western railwaymen. The expression is now obsolete.

6. *Mallet locomotive*—the largest type of steam locomotive; usually an articulated cross-compound engine, with one or more sets of pivoted driving wheels (see Fig. 15). Named after Anatole Mallet, a noted Swiss mechanical engineer, these huge locomotives were used almost exclusively in hauling heavy freights on mountain divisions before the advent of the electrics.

7. *Point*—the lead locomotion unit at the head end of a train. On an extra or nonscheduled train, the number of the locomotive is used to identify the train.

8. *Route-miles*—This is the actual distance from terminal to terminal points over which a railroad line is electrified, regardless of the number of electrified tracks (track-miles) along the right of way. Thus the Milwaukee Road—even though its main line right of way is mostly single track—is the longest electrified system in terms of route-miles; whereas the Pennsylvania (now part of the Penn-Central system) has by far the greatest extent of electrified track mileage (2150).

9. *Service brake*—the principle of railroad air braking is based on a continuous air pipe called the "train line," which, in a freight train, runs from the locomotive to the caboose. This line is pumped up to a reservoir pressure of 75 to 100 lbf/in^2 (55.2–68.9 N/cm^2) between sustained brake applications. Valve action on each car is such that a reduction in the train line pressure will apply the brakes in proportion to this reduction. For a "service" application, the air is exhausted from the train line at a metered rate. Total reduction in pressure, which may reach 30 lbf/in^2 (20.6 N/cm^2), is determined by the brake application time interval.

10. *Tender*—a permanently coupled vehicle containing the coal or oil fuel for a steam locomotive.

11. *Unglue*—rupture of a coupling between the cars of a train.

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Spacecraft infrared imaging

Systems engineering aspects

Because of the vehicle motion, coverage requirement, and "vertical" scan interrelationships in spacecraft systems, the vehicle actually becomes an integral part of the infrared imaging instrument

John J. Horan RCA

The first part of this article, which appeared in the June issue, described the nature of infrared scanners and the results of some satellite IR experiments. In this concluding installment, the parametric relationships between the scanner and the spacecraft are set forth. The suborbital velocity/altitude ratio is fixed for a satellite in a circular orbit. Thus, such parameters as coverage, resolution, and scan rate can be expressed in terms of altitude. Since the signal-to-noise ratio of the sensor output is also a function of many of these same parameters, an evaluation of the IR system performance can be made. Equations are developed for relating the sensor, the mission, and the spacecraft in terms of an overall IR system.

The two most important parameters of any imaging system are the resolution and the signal-to-noise ratio. As an example, the ability to see detail in a television picture is greatly reduced in the presence of interference and when the "snow" on the home television receiver becomes severe enough, the entire picture becomes unrecognizable. It has been stated that a minimum discernible picture has a signal-to-noise ratio (SNR) of 11.8 dB.[1] Infrared imagery requires not only imaging, but also provisions for radiometric measurements. If, for example, it is desired to measure a one-degree temperature change in a bank of clouds that has an average temperature of 200°K, a signal-to-noise ratio of 50 dB is required.

In IR imaging systems, the SNR is governed by many parameters, such as the sensitivity of the detector, the radiant energy focused on the detector by the optics, and the noise bandwidth of the system. The interrelationship of these parameters will be analyzed in the following discussion.

Scanning techniques

Many scanning combinations are possible from the numerous techniques and detectors that are available. Three of these combinations are shown in Fig. 1. Of these three, only the point-detector and linear-array scanners will be discussed.

Point-detector radiometer scanning systems. A point-detector radiometer scans the field of view in one axis by means of a mechanical actuating device. Two of the simplest mechanical scanning techniques are shown in Fig. 2. The configuration of Fig. 2(B) can be used as both a rotational and a reciprocating type of scanner. If a continuous rotation is applied to the mirror shaft, a scan is produced in which the optical axis scans at twice the rate of mirror rotation over an angle of 360 degrees. If a cam drive is substituted for the rotating shaft, a linear sweep with a rapid or flyback return is produced over a limited angle. This method yields reciprocating motion and, hence, reciprocating forces and momenta (which are much more difficult for the satellite stabilization system to compensate for than ordinary rotational motion).

Several of the feasible alternative scanning techniques require only rotational motion. A single-wedge prism when rotated causes the field of view to scan a cone; this technique has been used in several flight-proven horizon sensors.[2] Rotating a second wedge in the opposite direction produces a line scan. In relatively narrow spectral intervals, the transmission of these wedges can be made quite high. The principal difficulty in this type of scanning arises from the fact that the optical axis does not have a linear velocity but rather varies sinusoidally, and is accompanied by the usual bandwidth/resolution problems of sine-wave scan.

Linear-array radiometer scanning system. A linear-array radiometer achieves scanning of the field of view

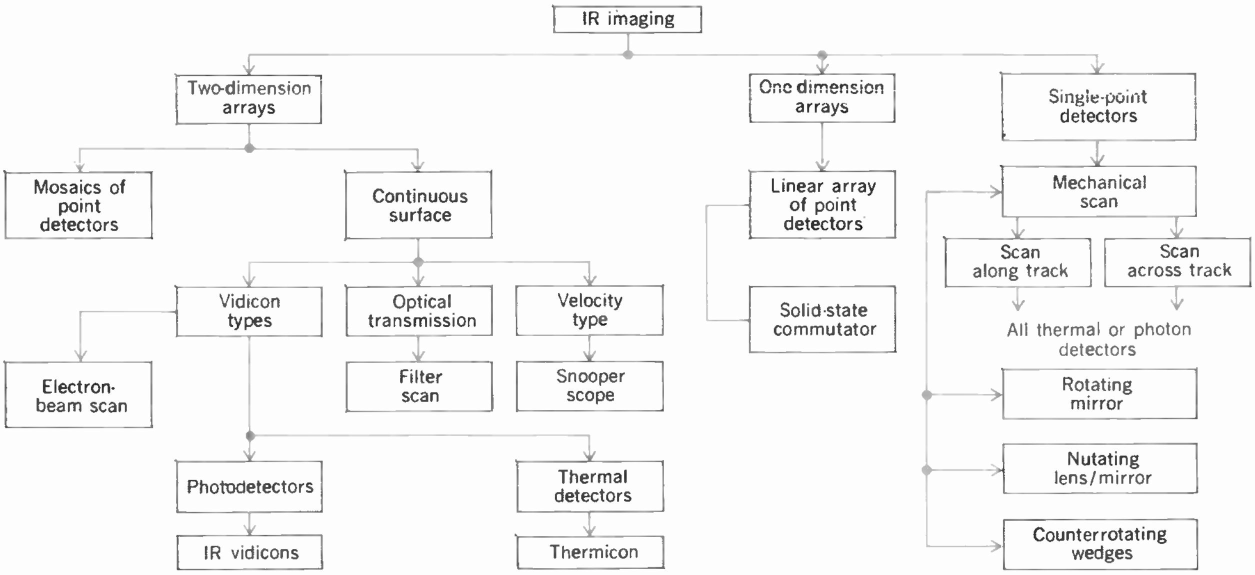


FIGURE 1. Detector and scan combinations for IR sensing.

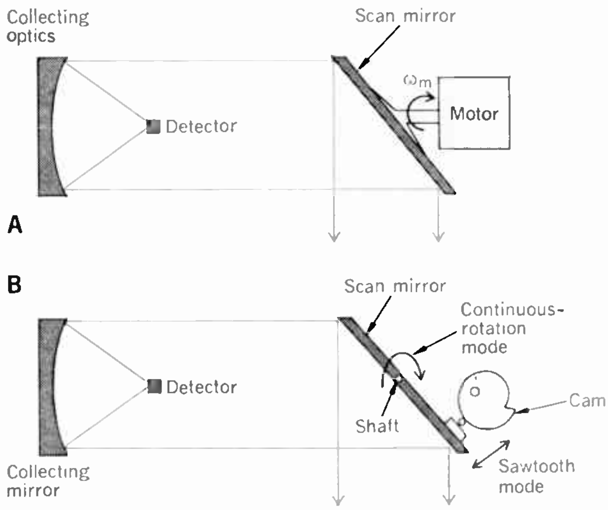


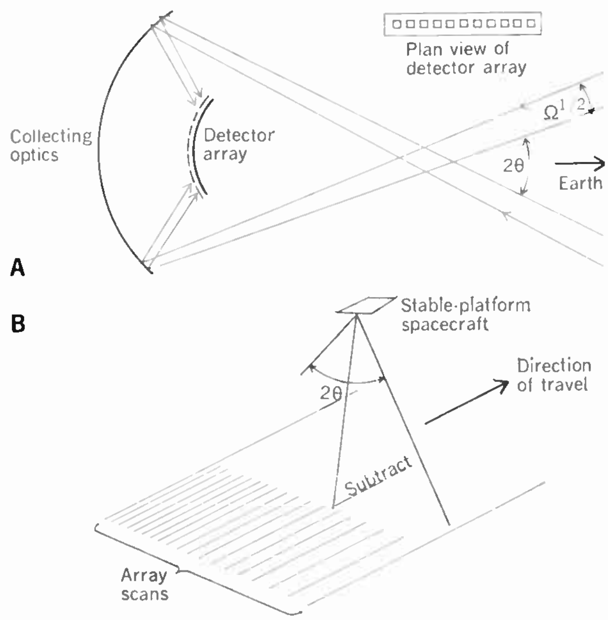
FIGURE 2. Scanning-mirror configurations. A—Rotating-mirror scanner. B—Rotating or sawtooth linear mirror scanner.

by means of electronic switching. For the sake of completeness, it is reasonable to consider an electronic scanning system for a stable platform. In such a system, an array of detectors is placed in the focal plane of the optical system. A spherical-optics system for such an application is shown in Fig. 3. The detector sizes and the associated optics are arranged to place the fields of view of each detector element side by side. An image is produced by the motion of the spacecraft around the earth as shown at the bottom of Fig. 3. Each detector output is sampled in turn, electronically, at a high rate. The advantage of this system is that the time-constant requirement is long, and thus the system sensitivity is improved. The system bandwidth, of course, is a function of the resolution and scanning rate. It can be shown that the constraints and equations derived for the mechanical scanners are also applicable to the array technique.

IR imaging analysis for mechanical scanning

The intent of this analysis is to predict the imaging system performance as a function of resolution for various platforms and coverage geometries. To accomplish this analysis, several parameters must first be investigated, then the results of these investigations must be combined. The initial area of consideration is the determination of the SNR of a radiometer from its detector, optical, and bandwidth properties. The next area of consideration is the spacecraft sensor geometry and the relationships between ground resolution, angular resolution, and coverage. Curves of zenith angle and scan angle for contiguous (and semicontiguous) global coverage are given. The extent of the geometric distortion, which is in only one dimension rather than in two (as in the case of a television picture), is considered. From the scanning angle and subpoint velocity, the number of resolution elements (which

FIGURE 3. Linear-array imaging radiometer. A—Linear-array geometry. B—Ground-scan pattern.



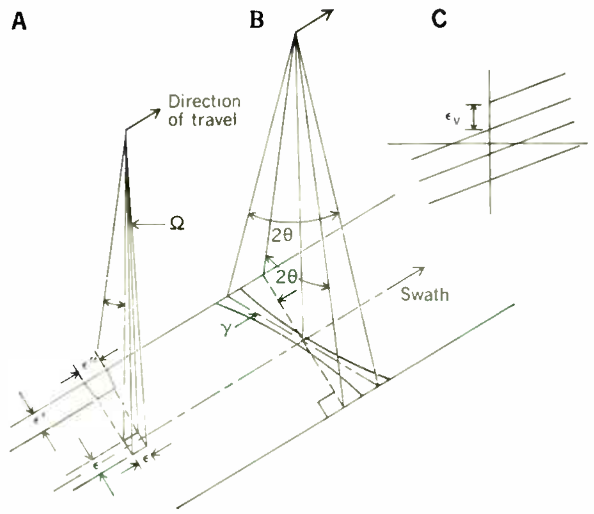
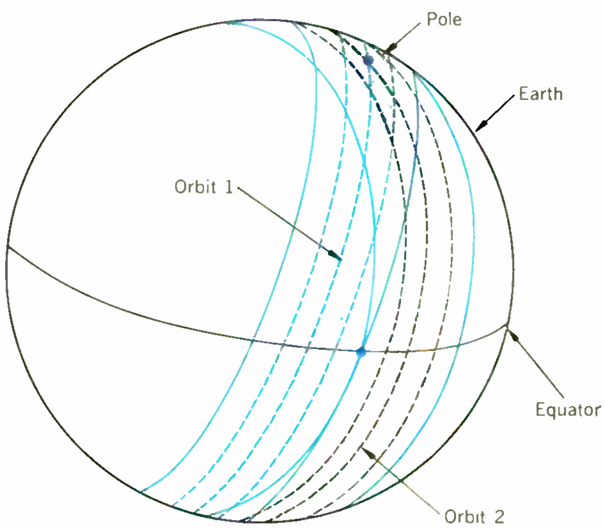


FIGURE 4. Geometry for IR analysis of sensor scan.

FIGURE 5. Scan coverage. Swath, shown between solid lines, is for contiguous coverage. Shaded area is for semicontiguous coverage.



determines the bandwidth) and the effect of "dead" time (during which no information is being collected) are considered. From these parameters, equations are developed that describe the required bandwidth (and hence the system SNR for a given detector and optics) in terms of various scan patterns and types of spacecraft stabilization.

Radiometer considerations. As has been stated, the SNR is dependent upon the radiant power focused on the detector, the detector sensitivity, and the noise bandwidth. The power focused on the detector can be expressed as

$$P_{det} = A_0 \Omega \eta N_r \quad (1)$$

The various symbols used throughout this discussion are listed in the glossary at the end of the article.

The detector signal is the sensitivity (described as "responsivity" by detector manufacturers and defined as volts out per watt in) multiplied by the power input P_{det}:

$$\text{Signal} = P_{det} \times \mathcal{R}$$

The noise in many detectors is the Johnson noise of the detector resistance R. The SNR is given by the following relationship:

$$\text{SNR} = \frac{P_{det}\,\mathcal{R}}{\sqrt{4KTR\Delta f}} \quad (2)$$

To illustrate the dependency of bandwidth upon field of view, assume that the optics size is commensurate with the size of the spacecraft and that the optical efficiency is fixed. Further assume that various systems are being compared, that all of them are viewing at the same target radiance, and that each system has identical optical components. Then A_0, η, K, T, N_r, R, and $\mathcal{R}$ may be expressed as a single constant, and Eq. (2) can be rewritten as

$$\text{SNR} = \frac{K_1 \Omega}{\sqrt{\Delta f}} \quad (3)$$

It becomes obvious that as the field of view becomes smaller, more elements are scanned per second; therefore the bandwidth increases and the SNR decreases rapidly.

Orbital geometric considerations. In order to limit this analysis to the area that may be practically implemented, several basic assumptions are made: (1) The scan is assumed to be derived from a mechanical motion, similar to one of those previously described. (2) Resolu-

FIGURE 6. Altitude vs. coverage (θ) and zenith (Z_c) angles.

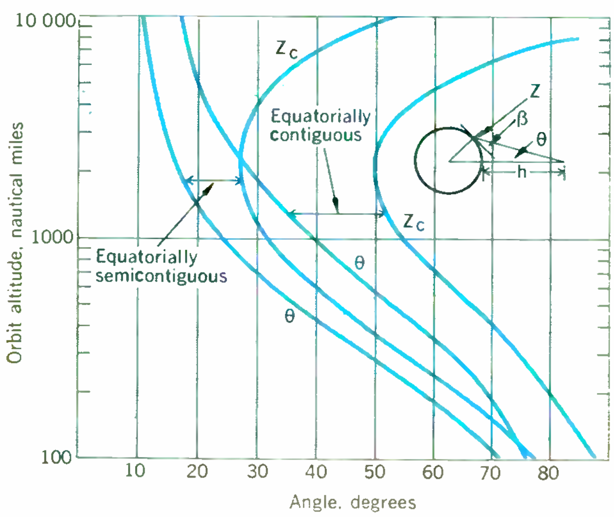
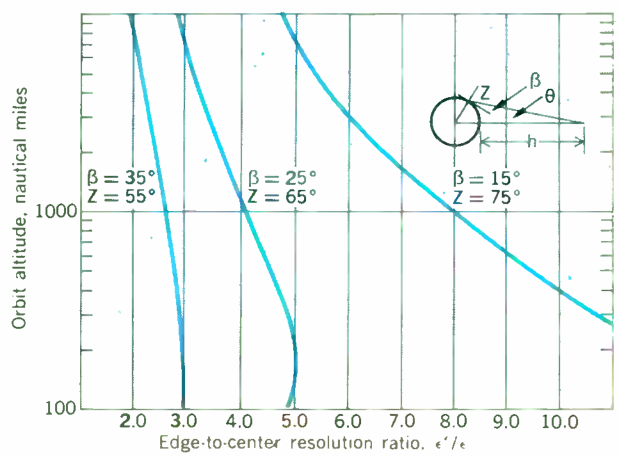


FIGURE 7. Altitude vs. edge-to-center resolution ratio at various zenith angles.



tion will be defined in terms of the instantaneous subtended angles, and will be related to ground resolution. (3) A flat earth will be assumed for the sensor scan considerations, but a spherical earth will be used for the orbital considerations. The following are definitions of terms used in this discussion:

1. *Swath.* A band, on the earth, that is the locus of the end points of the sensor scan. These end points are the intersection of the optic axis and the earth when the mirror has scanned an angle of θ degrees from the suborbital look angle (that is, the subpoint).

2. *Subpoint.* A point on the surface of the earth directly below the spacecraft, on a line between the spacecraft and the center of the earth.

3. *Scan pattern.* The locus of the intersection of the optical axis and the earth, as the optical axis is scanned.

It is assumed that an IR scanner mounted in a spacecraft, with an instantaneous field of view Ω, scans over the earth as shown in Fig. 4(A). If the locus of intersections of the optical axis and the earth is not a line perpendicular to the orbit plane [Fig. 4(B)], the scanning angle is $2\theta'$. When this locus is perpendicular to the orbit plane [Fig. 4(A)], γ is zero, and $2\theta'$ is equal to 2θ (the width of the swath). In either case, the locus is assumed to pass through the spacecraft subpoint and lie on a great circle of the earth. It is obvious that the number of resolution elements is a function of the subtrack width (and hence the angle 2θ). To determine the value of 2θ, the total required coverage must be considered. For example, if complete global coverage is required, the subtracks on successive orbits must be contiguous at the orbital equator; that is, each scanned swath must be contiguous, at the orbital equator; that is, each scanned swath must be contiguous, at the orbital equator, with the tracks of the previous and succeeding orbits. Semicontiguity can also be used to achieve this coverage. In this case, each track is half the distance required for contiguity; however, the spacecraft crosses the orbital equator twice per orbit. By the proper selection of the orbit, these dual crossings can be made to interleave so as to achieve global coverage. Figure 5 illustrates contiguous and semicontiguous coverage.

A relationship exists between altitude, zenith angle, and swath width, and it is usual to assume a swath width when deriving an expression for the zenith angle. However, by requiring only contiguity and semicontiguity at the orbital equator, some specific zenith angle (or angles) is established for each altitude. From the spacecraft orbital geometry, these zenith angles Z_c and the coverage half angles θ (shown in Fig. 6) can be computed.

In any case, unnecessarily large zenith angles should be avoided because of the large slant-path range and its attendant decrease in transmission, and because of the large ϵ''/ϵ ratio, which causes unnecessary overlap and distortion, while the increase in ϵ' decreases the ground resolution. This overlap and distortion is shown in Fig. 4. Note how the earth resolution element ϵ broadens to ϵ' and ϵ'' as the optical axis scans out from the subpoint.

As can be seen from Fig. 4, 100 percent coverage with line-to-line contiguity is achieved only when the lines are contiguous at the subpoint [Fig. 4(C)]. A regular element size at the subpoint (square or round) is distorted at the extremes of the scan pattern (rhomboids or ellipse). The ratio of the element size ϵ' in the direction of scan to the element size ϵ at the subpoint can be determined from the following expression:

$$\frac{\epsilon'}{\epsilon} = \frac{R_s}{h \sin\beta} = \frac{1 + \frac{R_e}{h}\sin\left[Z - \arcsin\left(\frac{\sin Z}{1 + h/R_e}\right)\right]}{\sin\beta \sin Z} \quad (4)$$

A plot of this equation is shown in Fig. 7.

Plots of ϵ'/ϵ are shown in Fig. 8 for contiguous and semicontiguous coverages as functions of the Z and θ angles taken from Fig. 6. If an ϵ'/ϵ ratio of three or less is considered, then for the contiguous case, operation must be limited to altitudes between 750 and 5600 nmi (1400 and 10 400 km), the minimum value of ϵ'/ϵ being 1.9 (at 2400 nmi). On the other hand, for the semicontiguous case, any altitude above 280 nmi will meet this ratio requirement; in fact, the ratio remains constant and near unity at all altitudes above 700 nmi. It is apparent that both the small zenith angle and the ϵ'/ϵ ratio of near unity make semicontiguous operation very desirable.

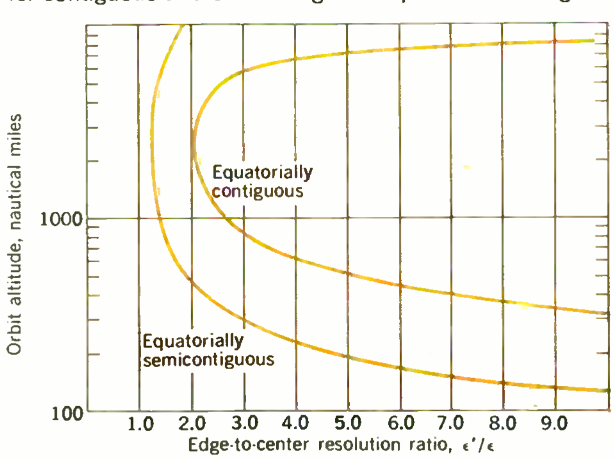
Sensor geometric considerations. The parameters, such as bandwidth, field of view, and scan rate, of sensors from either a stable platform or a spinning spacecraft will now be considered. Radiometric sensitivity is proportional to bandwidth, as will be described later. A comparison of sensor performance of the stable platform versus a spinning platform will be made, using the parameters as a function of altitude and coverage. This will permit a conclusion to be obtained as to altitude, coverage, and type of vehicle (spinning or stable platform).

The number of elements scanned can be determined from the coverage angle (2θ, noted previously) and the instantaneous field of view. The scan rate can be determined from the requirements of line-to-line contiguity and spacecraft velocity. Just as there is a requirement for scan-track contiguity, each line must also be contiguous with the next line at the subsatellite point.

Stable platform. As shown in Fig. 4, a scanner moves the field of view across the orbital subtrack, causing the locus of the optical axis to describe a line and/or curve through the subpoint at an angle γ to the orbit normal.

The scan angle is $2\theta'$ and is equal to 2θ when γ is 0. The element size, as previously defined, is ϵ at the subsatellite point; at the extremes of the scan it is ϵ', and along the direction of travel it is ϵ_t, as shown in Fig. 4(C).

FIGURE 8. Altitude vs. edge-to-center resolution ratio for contiguous and semicontiguous equatorial coverage.



The number of elements,* n_ϵ, scanned when the optical axis of the device scans an angle $2\theta'$ in Fig. 4 is given by

$$n_\epsilon = \frac{2\theta'}{\Omega^{1/2}} \tag{5}$$

The information rate that corresponds to the information bandwidth necessary to scan these elements in t_l seconds is

$$\Delta f = \frac{n_\epsilon}{2t_l} \tag{6}$$

From Eqs. (5) and (6), the active time per line is

$$t_l = \frac{\theta'}{\Omega^{1/2}\Delta f} \tag{7}$$

The spatial relationship between successive scan lines (that is, overlap, contiguous, gaps) affects the "vertical" resolution. For an imaging system, a relationship similar to the familiar "Kell factor" in television scanning should be considered in calculating vertical resolution.

Assuming that line-to-line contiguity has an overlap coefficient ρ the spacecraft moves a distance of $\rho\epsilon_r$ during the total time t_t from the start of one line to the start of the next line. Thus,

$$\rho\epsilon_r = v_s t_t$$

$$\epsilon = \epsilon_r \cos\gamma$$

$$\epsilon = \frac{\cos\gamma\, v_s t_t}{\rho} \tag{8}$$

The element size of the subpoint can also be expressed in terms of the field of view and the altitude as

$$\epsilon = \Omega^{1/2}h \tag{9}$$

From Eqs. (8) and (9),

$$\Omega^{1/2}h = \frac{\cos\gamma\, v_s t_t}{\rho}$$

Thus,

$$t_t = \frac{\Omega^{1/2}h\rho}{\cos\gamma\, v_s} \tag{10}$$

The ratio C of the time to scan a line to the total time (t_l/t_t) is an important parameter relating to the efficiency with which data are gathered. One minus this ratio, expressed as a percentage, is sometimes called "dead" time. This is the interval during which the mirror is scanning but not collecting information from the desired area of the target. Obviously, the ratio of active scan interval to total time should be made to approach unity to minimize the bandwidth. Care must be exercised in using this ratio, since it is a function of the spacecraft-scan geometry as well as the scan technique. To illustrate further, if the optical axis is scanned with a sawtooth motion, the active scan time is that interval required to deflect the axis through the angle 2θ, and the ratio C of active to total time can be made high. If continuous rotation of a 45-degree mirror, as shown in Fig. 2(A), is used, C is again the ratio of the interval to deflect the axis through the angle $2\theta'$ and through 360 degrees; from Fig. 6 it can be seen that, in this case, the ratio is small. If the coverage computations are based on a specific value for θ' (or θ, since they are related by the angle γ), the fact that the rotary mirror scanner covers an angle larger than $2\theta'$ does not improve the ratio C, inasmuch as this overscanning merely provides overlap from swath to swath. The ratio C is obtained as follows:

$$C = \frac{t_l}{t_t} = \frac{\theta'\cos\gamma\, v_s}{\Omega\Delta f h\rho} \tag{11}$$

Rewriting this expression in terms of the bandwidth:

$$\Delta f = \frac{\theta'\cos\gamma\, v_s}{\Omega h\rho C} \tag{11a}$$

Equation (11a) shows that bandwidth is directly proportional to the ratio v_s/h and inversely proportional to the field of view. This equation will be used in subsequent sections. If, however, it is rewritten in terms of ϵ [Eq. (9)], it becomes

$$\Delta f = K_2\frac{v_s h\theta'}{C\epsilon^2} \tag{12}$$

where

$$K_2 = \frac{\cos\gamma}{\rho} \quad \text{and} \quad \cos\gamma = \frac{\tan\theta}{\tan\theta'}$$

Note that the terms v_s/h and $v_s h$ appear in Eqs. (11a) and (12); they are plotted in Fig. 9 against spacecraft altitude.

Substituting Eq. (3) into (9) and (12) and rewriting the SNR terms yields

$$\text{SNR} = \frac{K_1\epsilon^3}{h^{3/2}}\sqrt{\frac{C}{K_2 v_s\theta}} \tag{13}$$

which indicates that the signal-to-noise ratio is proportional to the cube of the resolution element size. Thus, reducing the linear element size by a factor of 2 reduces the SNR by approximately one order of magnitude. Similarly, SNR can be expressed in terms of bandwidth as

$$\text{SNR} = \frac{K_3}{\Delta f^{3/2}} \tag{14}$$

Thus, by computing the bandwidth, a simple method for comparison of relative system signal-to-noise ratios may be obtained.

Bandwidth considerations. The variation in bandwidth (as a measure of radiometric performance) for any given ground-resolution element size as a function of altitude [Eq. (12)], will now be considered. The angle θ' can be assumed to be equal, or proportional, to the angle θ, which can be determined from Fig. 7. Equation (12) could be plotted on a relative basis by assuming that the angles γ and ρ are constant for all altitudes. However, as previously stated, there exist two cases for the value of the active-scan-time ratio C.

If a rotating-mirror scanner is employed, the active-scan-time ratio becomes a function of altitude. In the simplest case, C is directly proportional to θ; and Eq. (12) reduces to

$$\Delta f = K_1\frac{v_s h}{\epsilon^2} \tag{15}$$

Thus, the $v_s h\epsilon^{-2}$ curve in Fig. 9 is a plot of relative bandwidth for a rotating-mirror scan system except that the abscissa would be changed to "relative bandwidth." In order to compare rotating-mirror and sawtooth scan,

* The number of elements per scan line n_ϵ, being a function of θ', will vary as a function of the angle γ, even though the swath width 2θ remains constant.

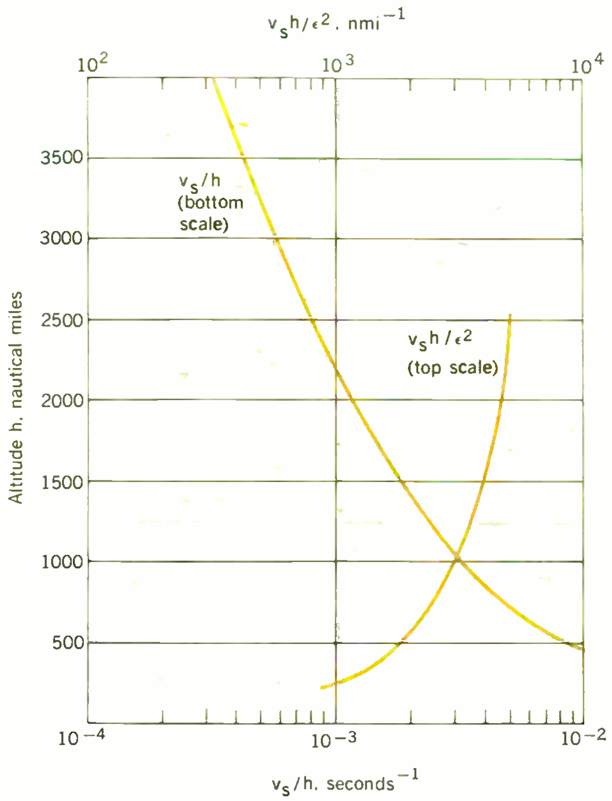


FIGURE 9. Altitude vs. v_s/h and $v_s h/\epsilon^2$.

FIGURE 10. Altitude vs. relative bandwidth.

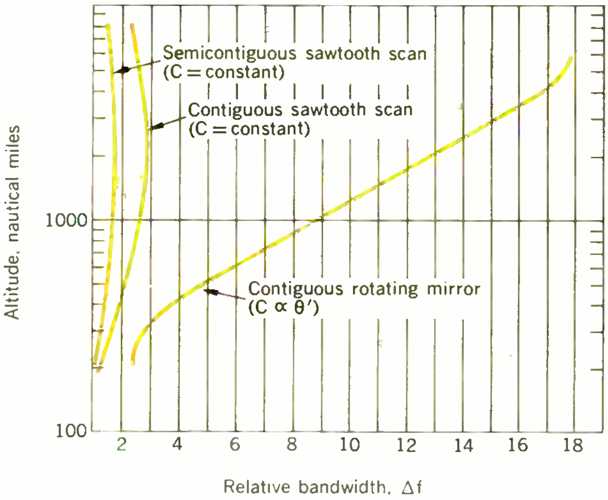
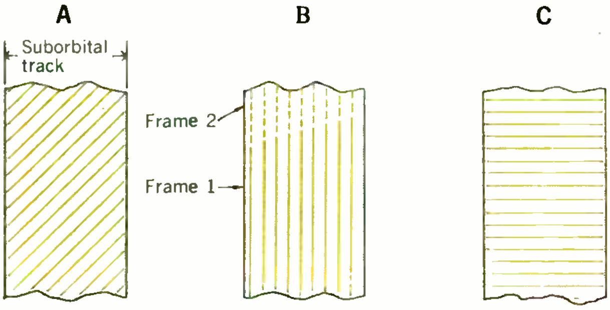


FIGURE 11. Ground-scan patterns. A: γ = 45 degrees. B: γ = 90 degrees. C: γ = 0 degrees.



assumptions must be made regarding the value of C for both cases. Equation (15) represents an assumption for a single mirror. The value of C may be increased by the use of multiple mirrors. For this discussion, computations shall be based on the simplest form, which can be easily scaled.

In the case of the sawtooth scan system, a value of 0.75 for C has been realized in existing ground systems and will be assumed here. It can be shown that, if

$$C_{mirror} = \frac{\theta'}{\pi} \quad \text{and} \quad C_{saw} = 0.75 \qquad (16)$$

then

$$\Delta f_{mirror} = \Delta f_{saw} \frac{2.35}{\theta} \qquad (16a)$$

Figure 10 shows relative bandwidth plotted against altitude for a constant-resolution element size (ϵ) for these conditions. As can be seen from this figure, the bandwidth for sawtooth scan and equatorial contiguity is greater than for semicontiguity, and from upwards of 400 nmi, semicontiguity requires only 15 percent change in bandwidth. The mirror scan bandwidth is greater, being nearly six times larger at 700 nmi than the sawtooth case. Therefore, it is obviously important to increase the active-scan-time ratio of continuous mirror scan, especially for moderately high-altitude spacecraft.

Spinning spacecraft. Thus far, only a stable platform for the IR imaging sensor has been considered. If the scanner were mounted in a spin-stabilized, wheel-oriented spacecraft, it would scan the subtrack during the portion of the vehicle's rotation that the IR imaging device is pointed toward the earth. On the basis of one scan per vehicle rotation, sawtooth scan does not provide an advantage over continuous mirror scan. Therefore, only a continuous mirror-scanning technique will be considered.

It is obvious that some synchronization must exist between the scanning mirror and the spacecraft spin. The simplest synchronization occurs when the angle γ is 0, 45, or 90 degrees. The angle γ is a function of the relative speeds of the IR scan and the vehicle spin. For any vehicle spin rate, the mirror scan rate (and hence the system bandwidth) must be highest for $\gamma = 0$. When $\gamma = 90$ degrees, the scanning mirror must move slower than the vehicle spin rate, establishing the least requirements for the scanning-mirror motor. The ground-scan tracks (which must in turn be displayed) are shown in Fig. 11.

1. When γ equals any angle except 90 degrees

As indicated in Fig. 12, the scan time for one line can be expressed in terms of the rotation of the spacecraft as

$$t_l = \frac{\sigma}{\omega} \qquad (17)$$

and the total time from line to line as

$$t_t = \frac{2\pi}{\omega} \qquad (18)$$

Thus, the ratio C_s for a spin-stabilized spacecraft is

$$C_s = \frac{\sigma}{2\pi} \qquad (19)$$

It can be shown that

$$\frac{\sigma}{2} = \tan^{-1}(\tan\theta' \sin\gamma) = \tan^{-1}(\tan\theta \tan\gamma) \qquad (20)$$

and $$\theta' = \tan^{-1}(\tan\theta \sec\gamma)$$

Substituting Eq. (19) into Eq. (20),

$$C_s = \frac{\tan^{-1}(\tan\theta \tan\gamma)}{\pi} \tag{21}$$

Substituting Eq. (21) into Eq. (11a) and converting θ to a geometric function,

$$\Delta f_s = \frac{\tan^{-1}(\tan\theta \sec\gamma)\cos\gamma\, v_s\pi}{\Omega hp \tan^{-1}(\tan\theta \tan\gamma)} \tag{22}$$

Equation (22) can now be solved for any angle (except 90 degrees). For the case where $\gamma = 45$ degrees, the addition of more than one scanner to utilize the time when the first scanner is pointed skyward is denoted by the factor S. Thus, for $\gamma = 45$ degrees,

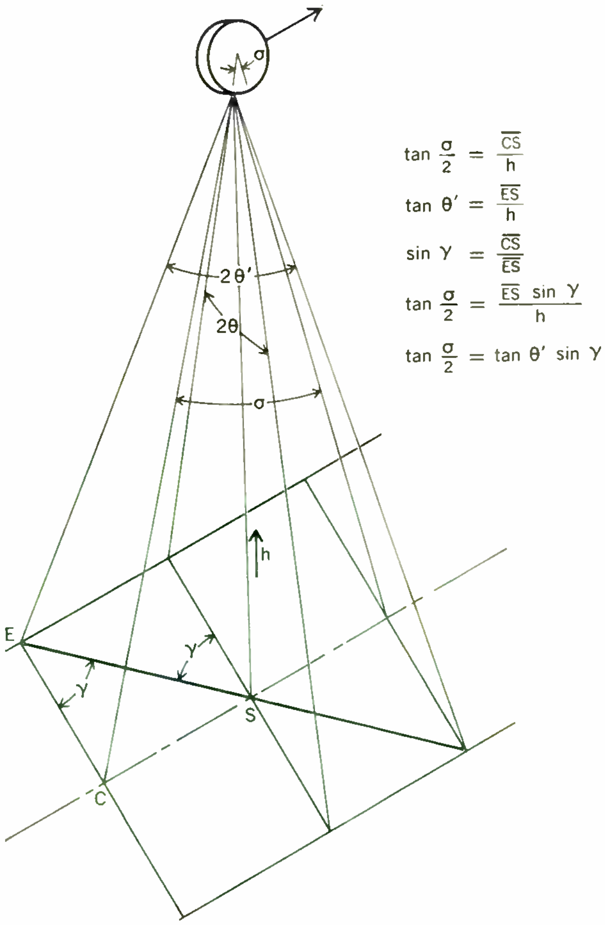
$$\Delta f_s = \frac{v_s\pi \tan^{-1}(\sqrt{2}\tan\theta)}{\sqrt{2}h\Omega p\theta S} \tag{23}$$

On a spinning spacecraft, the resolution and the spin rate are integrally related. From Eqs. (10) and (18),

$$\frac{\Omega^{1/2}hp}{\cos\gamma\, v_s} = t_l = \frac{2\pi}{\omega} \tag{24}$$

$$\Omega^{1/2} = \frac{2\pi v_s \cos\gamma}{\omega hp} \tag{24a}$$

FIGURE 12. Geometry for the analysis of sensor scan on a spinning spacecraft.



These data are plotted in Fig. 13. Altitude vs. spin rate for a constant ground resolution is plotted in Fig. 14.

2. When γ equals 90 degrees

Since Eq. (8) does not hold for $\gamma = 90$ degrees, this problem must be considered from the beginning. Equation (22) shows that on a spinning spacecraft the maximum bandwidth is needed at a γ of 90 degrees (or near 90 degrees). What this equation does not take into account is the limitation of the size of the scan angle $2\theta'$, which can go to infinity at a γ of 90 degrees. It should be noted here that the zenith-angle limitations for $\gamma = 45$ degrees, although not shown herein, can be derived in the same manner as the zenith-angle considerations for the stable-platform case, although obviously the zenith angle, and hence the slant-path length, must be greater than for γ of 0 degrees for the same subtrack coverage. Since slant-path length is an important factor in the radiometric objectives, the zenith angle for γ of 90 degrees shall be limited to that for γ of 45 degrees. Thus θ', which is equal to $\sigma/2$ for a γ of 90 degrees, must not exceed θ' for a γ of 45 degrees.

In addition, there is a requirement that during the scanning of n lines, which form a frame (that is, scan completely across the swath), the spacecraft must not have moved more than the length of one scan line. Put another way, the vehicle shall not move more than $1/n$ times the length of one scan line, where n is the total number of scan lines across the subtrack during the time required to scan one line. Further, from this requirement, the effects of satellite motion during one scan line are negligible.

By the first requirement, where γ is 45 degrees,

$$\frac{\sigma}{2} = \theta'_{90} = \theta'_{45} = \tan^{-1}\left(\tan\theta \sec\frac{\pi}{4}\right) \tag{25}$$

which reduces to

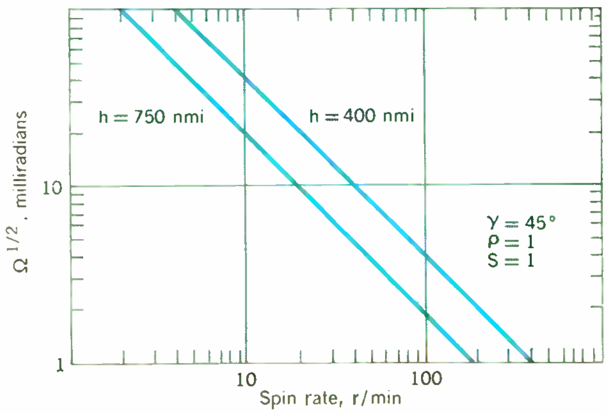
$$\sigma = 2\tan^{-1}(\sqrt{2}\tan\theta) \tag{25a}$$

From the reasoning for Eqs. (6) and (7), the expression for the time to scan a line along the subtrack, where the line scanning is done by the vehicle rotation, is

$$t_l = \frac{\sigma}{2\Omega^{1/2}\Delta f} \tag{26}$$

To meet the second condition (line-to-line contiguity), the total time per line multiplied by the number of lines n must

FIGURE 13. Field of view vs. spin rate.



equal the distance L that the spacecraft travels in one frame:

$$t_f n = \frac{L}{v_s} \quad (27)$$

since
$$L = 2h \tan \sigma/2 \quad (27a)$$

$$t_f = \frac{2h \tan \sigma/2}{n v_s} \quad (27b)$$

The number of lines n can be defined by the swath width and the resolution as follows:

$$n = \frac{2\theta}{\Omega^{1/2}} \quad (28)$$

Thus, substituting Eq. (28) into (27b),

$$t_f = \frac{h\Omega^{1/2} \tan \sigma/2}{\theta v_s} \quad (29)$$

Again, C_s (analogous to C for the stable platform) can be found by dividing Eq. (28) by Eq. (29):

$$C_s = \frac{t_l}{t_f} = \frac{\sigma\theta v_s}{2h\Omega\Delta f \tan \sigma/2} \quad (30)$$

But
$$C_s = \frac{\sigma}{2\pi}$$

therefore,
$$\Delta f = \frac{\pi\theta v_s}{h\Omega \tan \sigma/2} \quad (30a)$$

Substituting in Eq. (25a)

$$\Delta f = \frac{\pi\theta v_s}{\sqrt{2}\, h\Omega \tan \theta} \quad (31)$$

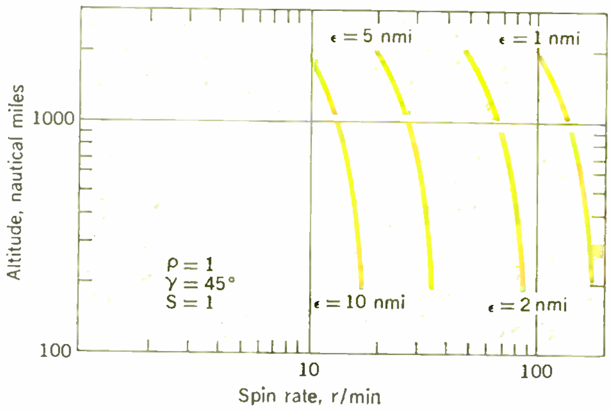
The ratio of the bandwidth scanning at $\gamma = 45$ degrees and $\gamma = 90$ degrees can now be explained as follows (assume $\rho = 1$ and $S = 1$):

$$\frac{\Delta f_{45}}{\Delta f_{90}} = \frac{\pi v_s \tan^{-1}(\sqrt{2}\tan\theta)/\sqrt{2}h\Omega\theta}{\pi\theta v_s/\sqrt{2}\,h\Omega \tan\theta} \quad (32)$$

$$\frac{\Delta f_{45}}{\Delta f_{90}} = \frac{\tan\theta \tan^{-1}(\sqrt{2}\tan\theta)}{\theta^2} \quad (32a)$$

This relationship is plotted in Fig. 15, where it can be seen that the bandwidth for γ of 45 degrees is greater than that required for γ of 90 degrees. For high-altitude spacecraft, where θ is small, the ratio approaches $\sqrt{2}$. However, for lower altitudes, where θ becomes large, the ratio increases rapidly. Even at moderate altitudes, if θ is increased for overlap considerations (at apparently no cost in bandwidth when a rotating-mirror scan is used), it must be remembered that the scan at γ of 90 degrees will have a significantly lower bandwidth.

FIGURE 14. Altitude vs. spin rate.



Bandwidth comparison

The bandwidth requirements for a spin system and those for a stable platform can now be compared. Equations (11) and (23) describe the bandwidths for these two cases. Examining these two equations reveals that they are the same except for the expression for the active time ratio C. The ratio of the bandwidths is then equal to the ratio of the C's. Scanning techniques can now be compared. For γ of 0 and continuous rotary-mirror scan on a stable platform, C is obtained from Eq. (16) as follows:

$$C_{stable} = \frac{\theta'}{\pi}$$

For a spinning spacecraft, C is obtained from Eq. (20) as follows:

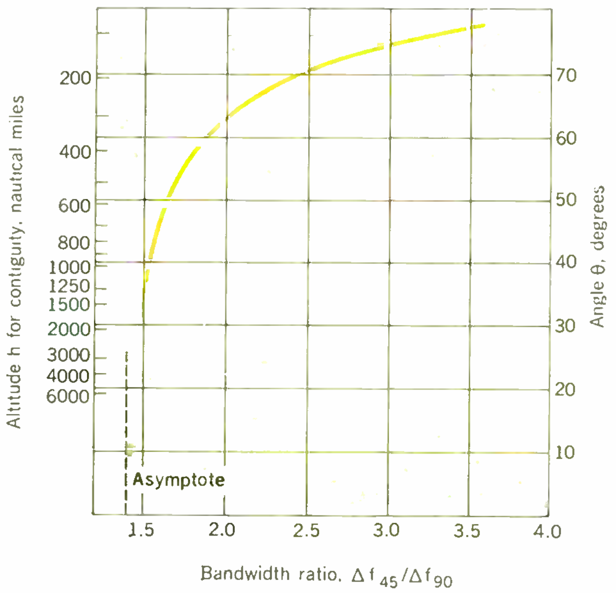
$$C_{spin} = \frac{\tan^{-1}(\tan\theta \tan\gamma)}{\pi} \quad (33)$$

$$C_{spin} = \frac{\tan\theta}{\pi} \quad \text{(for } \gamma = 45 \text{ degrees)}$$

Thus,
$$\frac{\Delta f_{spin}}{\Delta f_{stable}} = \frac{C_{spin}}{C_{stable}} = \frac{\tan\theta}{\theta} \quad (34)$$

Figure 16 shows the percentage increase of bandwidth required for the spin configuration over the stable-platform configuration, plotted against θ and altitude for contiguous coverage. As in the previous bandwidth comparison, the percentage of increase is a function of θ, regardless of whether the magnitude of θ is controlled by

FIGURE 15. Altitude and coverage angle vs. bandwidth ratio ($\Delta f_{45}/\Delta f_{90}$) for rotating spacecraft.



Glossary of symbols

A_0	Area of collecting optics
C	Active-scan-time ratio
h	Satellite altitude, nautical miles
k	Boltzmann's constant
L	Length of one scan line on the ground
n	Number of scan lines
N_T	Radiance of target
n_e	Number of resolution elements scanned
R	Detector resistance
R_e	Mean radius of the earth
R_s	Slant range
$\Re$	Detector responsivity
S	Factor for number of scanners
t_l	Time to scan one line
t_t	Total time from line to line
T	Absolute temperature, °K
v_s	Suborbital velocity
Z	Zenith angle
Z_c	Zenith angle for contiguous or semicontiguous coverage
β	Elevation angle
γ	Angle between the locus of the intersection of the scanned optical axis and the orbit plane normal, at the subpoint of the satellite
Δf	Bandwidth
ϵ	Ground-resolution element size, at nadir
ϵ_r	Ground-resolution line-to-line separation, at nadir
ϵ', ϵ''	Ground-resolution element sizes at extreme scan angle
η	Optical efficiency
θ	Half angular width of scanned subtrack perpendicular to orbit plane
θ'	Half angular width of scan
ρ	Line-to-line overlap coefficient
σ	Rotation angle of spacecraft during active scan
ω	Rotation rate of spinning satellite
Ω	Instantaneous solid angular field of view

coverage, as indicated by the altitude scale in Fig. 16, or by overlap requirement, in which case the altitude scale can be ignored.

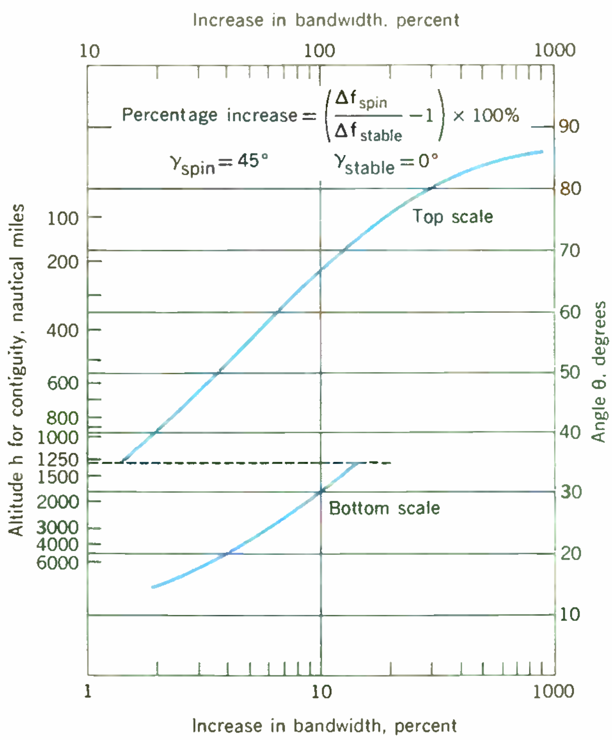
Conclusions

As can be seen from Fig. 10, the bandwidth is lowest and the sensitivity highest for a low-altitude stable platform with semicontiguous coverage, with a fixed active-scan-time ratio C (such as might be achieved with a sawtooth mirror system or counter rotating wedges). However, the bandwidth for such a system actually varies very little with altitude (that is, about 15 percent) from 450 to 4000 nmi (830 to 7400 km). A continuously rotating mirror scanner requires considerably greater bandwidth than a fixed-C system, and the bandwidth increases rapidly with altitude. For example, at 750 nmi (1400 km), the bandwidth for the continuously rotating mirror is three times that required for the sawtooth scan.

From Fig. 16 it can be seen that the bandwidth requirements for γ angles of 45 degrees with a rotating-mirror scan are nearly the same on a spinning spacecraft as on a stable spacecraft for moderate θ angles (which correspond to reasonable altitudes). For example, the increase in bandwidth imposed by using a spinning spacecraft is less than 2 to 1 at θ angles of 67.5 degrees, which corresponds to an altitude of 250 nmi (465 km) or higher. From Fig. 15 it can be seen that the bandwidth can be made nearly the same as the stable-platform system if γ on the rotating platform is made equal to 90 degrees.

Since a spinning vehicle presents a convenient means for using more than one scanner, it could have better performance than a stable platform with one sensor incorporating rotating-mirror scan, provided γ were made equal to 90 degrees and θ were kept to a reasonable value, say 60 degrees. This technique would provide contiguous coverage above 350 nmi (650 km). Using more than one sensor on a spinning vehicle also provides a type of redundancy, wherein the loss of one sensor merely reduces the resolution in one direction.

FIGURE 16. Percentage increase in required bandwidth of spin configuration over stable platform.



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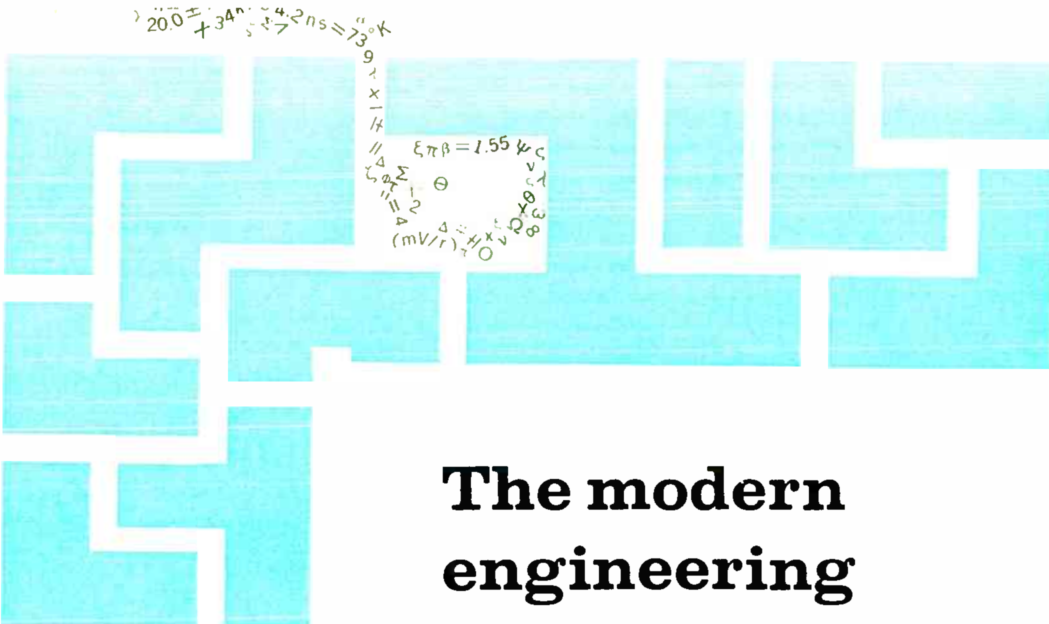


The modern engineering bandwagon

Engineering education is experiencing growing pains of the atomic age—the engineering curriculum increasingly emphasizes theoretical aspects, while subtly relegating practical problems to academic oblivion

A. D. Moore *The University of Michigan*

An outstanding educator in the field of electrical engineering expresses his concern over the trend to distort modern engineering curricula into a virtual maze of mathematics and theory. The practical aspects of electrical engineering are being neglected, since there is not enough time for both practical work and theory. To paraphrase, an expert on energy conversion theory could freeze to death in a lumberyard because he doesn't know how to light a fire. The editors of Spectrum have endeavored to present Professor Moore's thoughts, first expressed to the 2nd Canadian Conference on Electrical Engineering, in his own words and in his own style.

Quite a few bandwagons have been rolling in the past few years; and among them are the technical and scientific bandwagons crowding the American university campus. I personally can't join them all, having just so much time and capacity; but that doesn't mean I'm not as strongly attracted to them as is the next fellow.

I have nothing as such against any of these bright new curricular vehicles, such as computers, semiconductors, physics of the solid state, microelectronics and integrated circuits, systems engineering, information theory, holography, lasers and masers, radar, radio astronomy, cybernetics, servos, automation, the drive toward the metric system, or more emphasis on mathematics or on physics or what have you. As an electrical engineer, I know very well that these bandwagons carry a lot of electrical engineering. But I know just as well that they carry a lot of electrical science too, and when I see them crowding the campus I can't help wondering if they're not getting in each other's way. If they are, and if more of them are rolling all the time, then it's time to slow down the parade. We need hordes of electrical scientists, granted—but not at the expense of electrical engineers.

Based on an article appearing in *Ingenor 1*, a publication of the College of Engineering, University of Michigan, Ann Arbor, Autumn 1966.

The academic squeeze

The point is that each new bandwagon should be closely scrutinized, along with its riders. Should we put the whole wagon into the curricular parade, or just part of it? At the usual price of oversimplification, let us assume that the four-year undergraduate program is made up of 40 courses. We then have a curricular parade limited to 40 bandwagons; and for every new one added, an old one has to drop out. It really isn't that simple, of course. Instead of being eliminated outright, the older wagons are subjected to a gentle but persistent "squeeze."

The squeeze is obvious when a committee searches for class-hours that can be sacrificed to add some new course. (That's when the pressure comes to reduce graphics content, or to eliminate the rotating machinery lab, or what not.) The squeeze is less obvious, and much more difficult to control, when there's a gradual increase in the number of staff members who are electrical scientists and not engineers; when textbooks are adopted that offer more theory and less engineering; when the engineering curriculum slowly accumulates more and more courses that are really electrical science. Industrial employers, among others, are seriously questioning the validity of the squeeze, at least in the form of the graduates they are receiving from our universities.[1]

When the squeeze is on to reduce the hours required in some area, the defenders of that area should adapt the prevailing jargon to their own purposes. Is there still, anywhere in the country, an engineering school that requires Shop? If so, keep cool (and change the name from Shop to "Solid-State Transforms"). Is your Drawing Department due for another trimming? Stand firm (and change its name to the "Department of Integrated Linear Systems Communications").

Today we hear a lot about "invariant principles." There is a trend toward reducing apparently diverse mechanisms and phenomena to their invariant principles, and thus to teach in generalized terms—hence the recent introduction of Energy Conversion. And hence a little story about the dedicated professor who taught Energy Conversion at only the highest level of invariant principles. On a winter moose hunt, he got lost in a blizzard and stumbled into a cabin that was well supplied with firewood. But he froze to death. No one had ever taught him how to strike a match.

The fact is that, broadly speaking, few of us learn deductively—from the general to the specific. We learn, rather, inductively—from the specific to the general. The power of generalization can't be assumed; it requires a certain degree of maturity and experience. Our trends toward high-level, theoretical, invariant-principle, generalized teaching could easily lift our students' heads so high that even their toes don't touch ground. In fact, this may already have happened in some quarters—but more of this later.

One symptom of the "generalizing" trend is the recent onset of the generalized or universal laboratory machine, which I describe as a device that does many things poorly and nothing well. This reminds me of a comment made recently by Dr. James B. Fisk, president of Bell Laboratories: "An engineer does not make elegant solutions of nonexistent problems. Neither does he make sloppy solutions of real problems."

I wish that Dr. Fisk's statement could hang on the wall of every engineering classroom and laboratory, that it could be read aloud whenever a curriculum revision committee is called to order, and that every author of a new text could have it to look at, right above his typewriter, preferably in neon.

Alienation of engineering

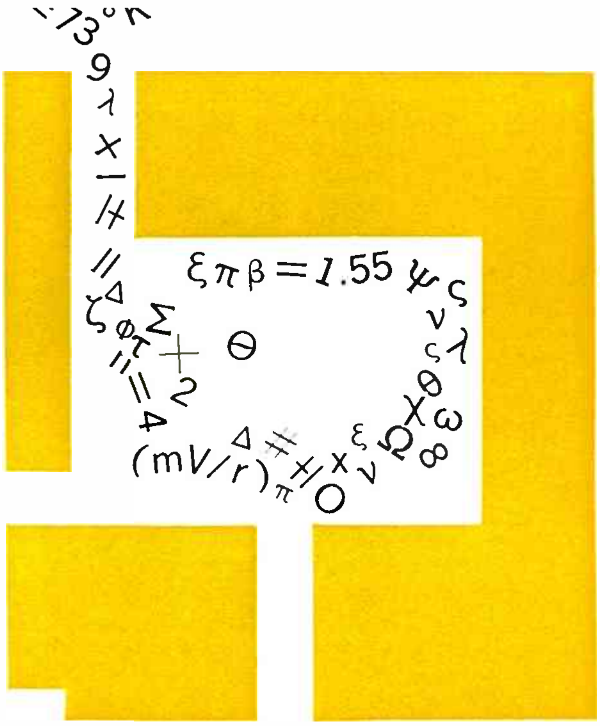
John R. Pierce, another Bell Laboratories man, has spoken up on the subject.[2] From Pierce's important contributions to Project Echo and to various advances in electronics, we might expect him to be strongly biased in favor of far-out, wild-blue researches. But no, he expresses concern that: "...engineering is being alienated from the productive civilian economy which makes possible both our good life and our expenditure on defense and space."

Continuing, he says:

"...we are doing this inadvertently, through the nature and magnitude of the support given to university engineering research by defense and space agencies. If we are to remain strong and prosperous, we must take thought and action to draw engineering education and civilian industry closer together... Whatever influences university engineering research inevitably and irresistibly influences all of engineering education and all engineering students."

But more of this later. I cast my nets wide, you see, and am bound to catch something.

The growth of scientific and engineering research during the past 20 years (much of it stimulated by defense and space needs) is without doubt an awesome phenomenon. Who has been largely responsible for it? To answer



that, step back in time with me for a moment. When I joined the staff at the University of Michigan in 1916, I became part of an engineering faculty who wanted to *teach*. That's why we were there. Nearly every man was at least a good teacher, and quite a few were excellent. There weren't many Ph.D.'s among them, and few of the Ph.D.'s did much research. Some did consulting; in fact, some of them did too much consulting. Now this sort of faculty was prevalent through the great depression, and at least until 1941. Let us call it the "old-time" faculty.

The Ph.D. mill

Obviously, the engineering graduates prominent in business and industry in 1941 had been trained by old-time faculties. Since it usually takes 20 years or so for a graduate to achieve a top position, it follows that the engineering graduates prominent in 1961 were mostly products of the old-time faculties. This leads to an interesting conclusion: Insofar as engineers were *in charge*, the vast proliferation of new things in science and engineering came about under the guidance of engineers trained in the "old school." It would seem that the relative simplicity of engineering education in the older days did the country no great harm. The proliferation did occur—with astounding speed and to an astounding extent.

In contrast, the modern engineering faculty is largely and increasingly staffed by men with Ph.D. degrees. For advancement, the edict is the familiar "publish or perish!" As has been pointed out on all sides, faculties are sometimes enlarged on grounds of research interests rather than teaching ability. Flooded with students as we are, much of our teaching is done (and apparently *must* be done) by teaching fellows—that is, by men on their way to the Ph.D. degree, many of whom can't teach and are devoid of industrial experience. And we have now reached the point at which the Ph.D. mill is self-perpetuating.

Moreover, many of our engineering textbooks are written by specialists in the sciences. These books are often stripped of the historical and biographical items that stand as vital elements in our technical culture. To find hardware pictured in such books is getting to be a real surprise. In short, our texts are becoming completely mathematical and theoretical. How much engineering do they leave room for? No wonder an official of a major electrical manufacturing company tells me, "It is impossible to hire a designer of rotating machinery."

Not long ago I read a little book by D. K. C. MacDonald, who takes the reader back in time and space to the Scotland of the 1830s. He tells of a little boy who was forever pestering his delighted parents with questions—having them explain the flow of water, making them follow out the elaborate system of "call wires" used in their large house—and was never satisfied until he had mastered a mechanism by understanding it. When the boy grew up he became head of the Cavendish Laboratory, there taking the Chair of *Experimental* Physics. For James Clerk Maxwell was first and foremost an experimentalist and a builder of equipment. He based his thought and work on material reality. What if Maxwell came alive today and found how most of us are trying to teach purified electricity and magnetism? I think he'd say, "My equations, by themselves, or even with illustrative solutions as examples, can mean little to your students. Why don't you have them conduct their own experiments, and get their own firsthand experience with some of Faraday's work, or with appropriate equipment you've dreamed up? Don't you ever have them show up a magnetic field with some iron filings? Don't you ever make an electric field portray itself in some manner? If you give a man nothing but theory and mathematics, how do you expect him ever to acquire a *feeling* for fields?"

Mathematical de-emphasis

Mention of Faraday brings up another bit of worry. Faraday was a physical, not a mathematical, thinker. It appears certain that he had next to no mind for mathematics. It is nearly as certain that Charles Darwin was a mathematical illiterate. In our undergraduate and graduate curricula we have set up requirements that would exclude both men; if they did somehow get into a graduate program, they would soon be hustled out of it. The world certainly needs more such thinkers, and the race offers many men who have all the gifts except the gift for mathematics. Don't we owe them a bit of worry?

Faraday, who did such a phenomenal job of self-education, started out as a poor lecturer and turned himself into the master of the lecture-demonstration. This took up some of his finest energies, and is the means by which he presented many of his outstanding discoveries. Yet I am familiar with no recent work in electrical engineering that has mentioned him as a great teacher and a great demonstrator. There used to be many such teachers, you know. During lecture tours I've been approached many times, after a demonstration, by men with much the same reminiscence; they wanted to tell me of the great teacher they had had (often in physics or chemistry) who *demonstrated*. That was the teacher they remembered, and it was his course that they recalled more clearly than any other. Must the great teacher be entirely supplanted by the closed-circuit television set? One wonders. Or if television revives him instead, one wonders if he can survive the guidance of a curriculum committee.

As for John Pierce, what specifically did he mean when he said that we're neglecting our civilian economy? He didn't offer a list of items, maybe because one is so easy to work out. What about power apparatus and auxiliaries? The transformation and distribution of power? Motors and control? For the household: clothes washers, dish washers, freezers, refrigerators, ranges, grills, toasters, mixers, vacuum cleaners, fans? For the house: wiring, fusing, and so on? What about the whole subject of storage batteries? What about transport: electric railways, ship propulsion, submarines, electric cars, electric trucks, cars, subways, elevators? For the auto: starting, lighting, ignition? What about the manufacture of cable, wire, insulation? And electrostatics, with its three main divisions of precipitation, separation, and coating? What about welding, and the power supply for it? What about electric heating for the home, electric furnaces, industrial electric heating via resistance heating, induction heating, dielectric heating? What about illumination for home, street, highway, theater, parks?

These and countless other items make up the contribution of a single engineering field—electrical engineering—to the civilian economy. These are major productive activities through which taxable profits are made; and it is taxes, to labor the obvious, that support the nation's space and defense efforts. Yet these are the very activities we have been dropping by the wayside, to be picked up by those "to whom it may concern." When a professor of electrical engineering dismisses these activities by calling them "old hat" and fully developed, he is half right (the first half). But surely they have not even approached full development. If they have not been advanced in recent years, neglect is largely to blame. Who will claim that in this year, *anything* in our rampant technology is not subject to challenge and to new development?

Finally, let me cast a net toward the end product of our academic effort—the engineering graduate.

One of my earlier students (a bona fide product of the old-time faculty) now heads one of the most important research laboratories at General Electric. To quote him, "It used to be that when I gave a Ph.D. a problem, he was happy. Nowadays, if I give him a problem, he is happy *provided* it fits in with his training. If it doesn't fit in with his training, he doesn't know what to do." Another of my students is far up in a giant organization, for which only the best are recruited. He himself goes out to recruit the best for it—the best being top Ph.D.'s. He tells me: "After we get them, we can't trust their graphics until we retrain them." (Engineers with poor graphics!)

Inventories: an evaluation technique

As distressing as these random items may be, they don't rank with what I call the "Inventories." I dreamed up these Inventories as a way of investigating the background of senior undergraduate students in electrical engineering. In administering the Inventories, I made it plain that no student's standing would in any way be affected by results. The locale will remain confidential. During the past few years I've lectured at some 40 colleges and universities, and there was opportunity at any one of them. The school I chose would certainly be rated among the top 20 in the United States; many would rate it high on the list.

Inventory I. This concerned 48 of the most common materials in electrical engineering. In Part I, the student was to mark the materials which, in the ordinary sense of the word, are conductors. The scoring was: (Correct) minus (Incorrect) minus (Unknown). Among 45 second-semester seniors, there were two perfect scores. The class average was 51 percent; the low score was −7. In Part II, the student was to mark the materials *ordinarily* considered to be magnetic, the criterion being obvious attraction of a considerable chunk by a strong magnet. The scoring was: (Correct) minus (Incorrect). There were five perfect scores. The class average was −2.95; the low score was −26.

Inventory 2. In this, a magnet (with poles marked) was held with the jaws down. A closed rectangular conducting loop was held with its upper side in the air gap, and was allowed to fall. In Part I, the problem was: If there is a current, show it properly with an arrow. Of 44 arrows shown, 31 were shown correctly. In Part II, the problem was: If there is a force on the loop, show it with an arrow. Here, 20 arrows were shown correctly. Four seniors showed a horizontal force, two, a rotary force; one, a diagonal force; two, a force in line with the conductor; one stated "no force," and three left the whole thing blank.

Inventory 3. In this, the three standard views of a cubical glass box were shown, with a compass mounted on top of the box, pointing parallel to the edges, and with N marked on one end. Two views of a simple round coil were shown nearby; the coil was just big enough to fit nicely into the box. The task was to draw the coil inside the box in all three views, and to show by an arrow the current that would make the compass do what it was doing. Among the 45 seniors, 18 responded with correct drawings. Seventeen others got the coil properly, but indicated the wrong current. Several responded with incompatible coil views. As a side issue, I rated the quality of coil sketches as follows: 4 good, 12 acceptable, 17 poor, 8 miserable, and 4 utterly miserable.

Inventory 4. This had to do with a tin can with a lid. When the lid was removed, a metal ball could be seen hanging from it by an insulating thread, the thread and ball being definitely off-center. It was assumed that can and lid were handled by insulating tongs, and that a charge was placed on the ball. In Part I, the lid was replaced carefully, without letting the ball touch. There were five questions about the several charges present, and the force effect, if any. Forty-five seniors turned in 33 sets of correct answers. In Part II, the can was first tilted, to let the ball touch the sides. There were five more questions, but only one need be taken up here. Faraday's famous ice pail experiment, and some of our modern teaching, failed to prevail: 23 men left a charge on the ball!

Inventory 5. This showed a magnetic circuit, with a coil around a central member and with the iron going symmetrically around the right and left sides of the coil. The iron was not closed; there were identical air gaps at each side. The seniors were given the number of coil turns and the ampere-turns of magnetomotive force acting on one gap. Their problem was to find the coil current. Of the 45 answers, four were correct.

Inventory 6. For this, a sketch was shown that looked much like a D'Arsonval instrument; it contained a magnet, a round armature, and a one-turn coil. The coil leads come out, through slip rings, to a voltmeter. The turn was to be rotated momentarily, producing a voltage. The seniors were given the flux density, axial length, and the speed of each side of the turn in inches per second. Their problem was to find the instantaneous volts induced. Of the 43 answers, seven were correct, and eight gave one-half the correct value. The other answers gave a fantastic array of values. I should for a special reason quote one answer. For B = 70 000 lines per square inch, axial length = 1 inch, and speed = 600 inches per second, the answer was

$$\frac{(600)^2 \times 70\,000 \times 1}{R}$$

The special reason for quoting it? I was informed that this chap was a teaching assistant!

The results of the Inventories speak for themselves. If a school lays great stress on all the ramifications of Maxwell's equations but permits men to graduate with so faltering a grasp of the rudiments, Maxwell might have good cause to raise his eyebrows. Gentlest of men, he might even be moved to speak sharply.

A possible solution

This is no place for me to be making general recommendations. And in no sense am I recommending a return to the subjects and methods of 1935. (Please don't mistake my message to be *that*!) But I do have one suggestion for any department that finds itself turning out men who cannot answer the simplest and most basic theoretical questions. If, somehow, ground-level knowledge and capability have been ignored by the college, and are not supplied by the high school, and are not picked up by students somewhere along the way, then a hurdle might well be introduced, perhaps at the end of the third year of undergraduate study. In order to acquire *senior status*, every student would have to get himself over this hurdle. He would know of its existence early and would have to prepare for it on his own. It would consist of just such classically simple Inventories as those I have mentioned.

How do I, from my vantage point of years and experience, account for the decline of practical engineering knowledge and skills? (The decline must be obvious to all engineers, young or old, whether or not they consider it a bad thing.) Well, in earlier days, life was far simpler. We had *time*, and we had teachers and books, and from them we learned something of what I have called *technical culture*. Like all human tribes, engineers have their myths and legends, their heroes and history, their social rules and their political structure. To ignore this fact of tribal, cultural life is to ignore not only half the interest but half the *art* of engineering. Failure to transmit a sense of this culture to our students is to deprive them of full identification in and with their professional roles.

It is precisely this sort of culture that has been all but lost in the crush of bandwagons. Our teachers seem to know little engineering history, and what they do know they have no time to convey. Our texts make a point of ignoring such unscientific (and therefore irrelevant) matters. Yes, these are busy times, and we must get on with it, in a hurry.

But before the next bandwagon starts rolling, I think we should all start checking credentials. Else we'll find that in trying to be all things to all men—big and bright and bouncy—we have failed some men in some vital way.

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Atmospheric effects on propagation at millimeter wavelengths

Millimeter waves, with their relatively large available bandwidths, are being investigated as the logical means for meeting earth-to-space communication requirements. One important factor is the attenuation under a variety of atmospheric conditions

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In order to meet future earth-to-space communication needs, new regions of the electromagnetic spectrum must be utilized. This article discusses the feasibility of using the millimeter-wave region. It is shown, for example, that for clear-sky conditions the effects of the atmosphere on propagation at frequencies of 15 and 35 GHz are very small. However, the attenuation increases significantly under conditions of heavy cloud cover and precipitation. On the basis of these results it is evident that atmospheric attenuation is sufficiently low in selected regions of the millimeter-wavelength spectrum to permit wide-band earth-to-space communications with moderate reliability. For high reliability the high attenuation due to heavy rainfall must be overcome either by the use of space diversity techniques or by locating the ground terminal in a dry climate.

If future earth-to-space communication needs are to be satisfied, it will be necessary to exploit new regions of the electromagnetic spectrum. Although we do not contend that millimeter waves are more suitable for earth-to-space communications than the longer wavelengths, the spectrum up to 10 GHz is slowly becoming overcrowded. It seems reasonable, therefore, to assume that the time will come when the spectrum will have to be extended. It is chiefly for this reason that millimeter waves, with their large available bandwidths, are being considered. In addition, high-gain, high-resolution antennas of moderate size—along with the compact components typical of this wavelength—are particularly applicable as space-vehicle instrumentation. Moreover, millimeter wavelengths may be utilized for secure communications for space-to-space links by operation at wavelengths at which there is high atmospheric attenuation.

The frequency region most suitable for propagation through the atmosphere is around 35 GHz ($\lambda \approx 8$ mm). The region around 94 GHz ($\lambda \approx 3.2$ mm) also shows relatively low attenuation; however, it is not included in this study because the state of the art of components at that frequency is not as far advanced as at 35 GHz, and atmospheric effects are more severe at 94 GHz. Consideration is also being given to the region near 15 GHz ($\lambda \approx 2.0$ cm). This region, though not strictly in the millimeter-wave band, is for the most part unallocated and has limitations similar to those at 35 GHz.

Millimeter waves are attenuated by atmospheric absorption, refraction, and scattering. The degree of attenuation is related in a complex way to meteorological conditions along the path of propagation. Under certain conditions the attenuation is insignificant and at other times its effects are prohibitive. In some cases it is varying rapidly and in other instances it is varying slowly. Although some types of attenuation have been explained by theory, others have not been completely accounted for. Actually, it is only the lower atmosphere (troposphere) that affects propagation at the wavelengths considered. For an earth-to-space communications link, the amount of the troposphere traversed decreases as the satellite approaches zenith, and thus atmospheric effects become less severe.

Theoretical considerations

The principal atmospheric gases that attenuate millimeter waves (through an absorption process) are water vapor and oxygen.[1] Water vapor and oxygen molecules have permanent electric and magnetic dipole moments, respectively, which, when excited by an electromagnetic wave, oscillate and rotate with many degrees of freedom, each associated with a quantized energy level $h\nu$. Thus the molecules absorb discrete amounts of energy from the wave and are raised to a higher energy level; in returning to a lower level they reradiate energy isotropically, and therefore the net result is an attenuation of the incident wave. Figure 1 shows atmospheric attenuation as a function of wavelength for typical clear-sky conditions. Water vapor has resonances at frequencies of about 22 GHz ($\lambda \approx$ 1.35 cm) and 180 GHz ($\lambda \approx$ 1.6 mm). Oxygen has 25 closely spaced resonances (measured), occurring in the region of 60 GHz ($\lambda \approx$ 5 mm); however, because of pressure broadening, the individual lines overlap to form a continuous region of absorption at elevations near sea level. An additional oxygen resonance occurs in the region of 120 GHz ($\lambda \approx$ 2.5 mm). The shapes of the water-vapor resonance curves are dependent on atmospheric temperature, pressure, and partial pressure of water vapor, whereas the shapes of the oxygen resonance lines are a function of atmospheric temperature and pressure. A resonance line is generally described by an empirically determined parameter denoted as the line-breadth constant. It should be noted in Fig. 1 that atmospheric attenuation decreases with increasing altitude; this follows from the fact that the density of the gases decreases with altitude.

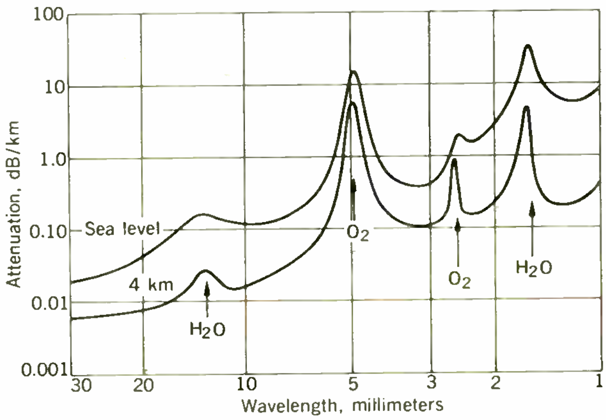
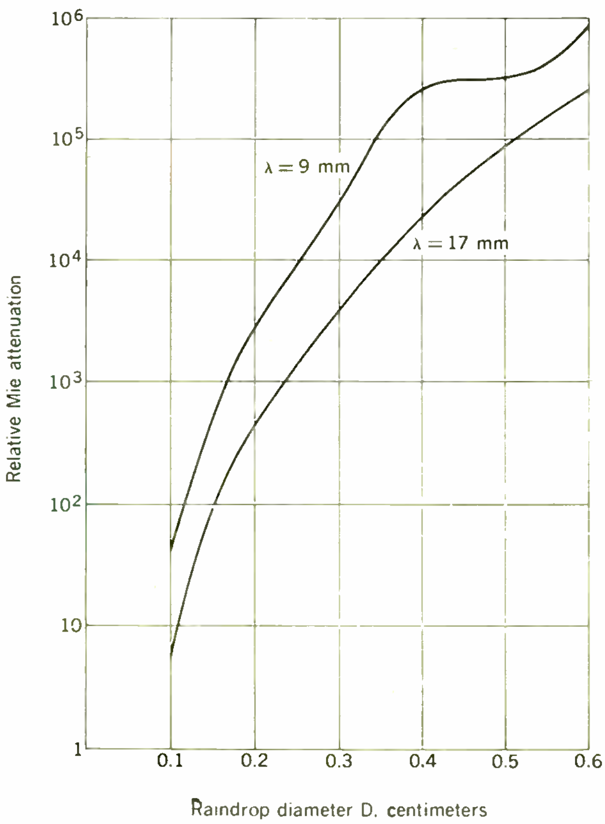


FIGURE 1. Attenuation at millimeter wavelengths.

FIGURE 2. Attenuation vs. raindrop diameter.[2]



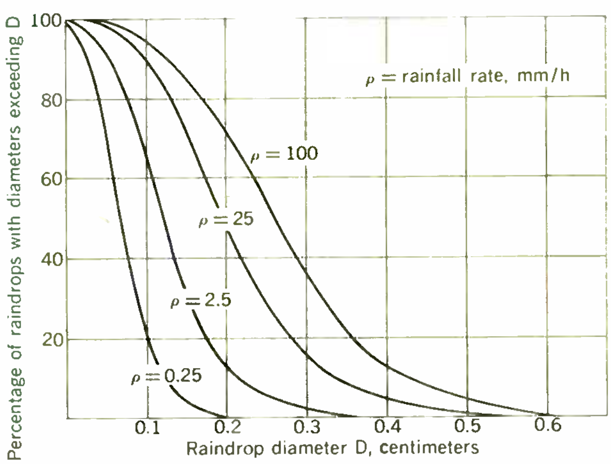
Attenuation by clouds and precipitation.[2] Clouds and precipitation attenuate electromagnetic waves through absorption and scattering processes. Equations for both types of attenuation have been derived from the Mie (1908) theory,[3] which treats spherical particles of any material in a nonabsorbing medium. If the droplets are very small (diameter $\ll$ wavelength) the Rayleigh approximation can be applied.

Since cloud droplets are generally less than 100 μm in diameter, the Rayleigh approximation holds. Attenuation from water clouds is much larger than that from ice clouds; moreover, for both cases the losses are due principally to absorption rather than scattering. Therefore, the attenuation depends more on total liquid-water content than on droplet-size distribution.

Attenuation caused by rain has been calculated from Mie theory and plotted as a function of drop diameter in Fig. 2. It can be seen that attenuation increases very rapidly with drop size. Figure 3 shows that there is reasonably good correlation between raindrop size and rainfall rate and that drop size increases with rainfall rate.[4] Typical drop sizes vary from about 1 mm to 6 mm in diameter and are therefore of the order of a wavelength in size in the millimeter-wave region. By means of these curves it is possible to estimate attenuation as a function of rainfall rate,[5] as shown in Fig. 4.

It has been found that attenuation resulting from rain is approximately proportional to the number of droplets per unit volume and is slightly greater for nonspherical particles than for spherical particles of the same volume. Dry snow or hail causes relatively low attenuation com-

FIGURE 3. Raindrop size vs. rainfall rate.[4]



pared with rain having equal liquid-water content, whereas wet snow has been shown to attenuate more strongly than water spheres of the same volume.

Refraction. An electromagnetic wave upon passing from one medium to another undergoes a change in velocity and if it enters the second medium obliquely it experiences a bending called refraction. The index of refraction of the earth's atmosphere at microwave frequencies is given by the expression[6]

$$N = (n - 1) \times 10^6 = 77.6 \frac{P}{T} + 3.73 \times 10^5 \frac{e}{T^2} \quad (1)$$

where

n = index of refraction
N = index of refraction (alternative form)
P = air pressure, millibars
T = temperature, °K
e = partial pressure of water vapor, millibars

For a standard atmosphere, assumed to consist of horizontally stratified layers, P and e decrease rapidly with height and T decreases slowly. Therefore, n decreases with height and a wave passing from a lower to upper layer is bent downward. Under these conditions, the apparent position of a source outside the lower atmosphere appears at an elevation angle slightly greater than that corresponding to the true position. The refraction correction for a standard atmosphere is shown in Fig. 5 as a function of elevation angle for both microwave and optical wavelengths. For a dry atmosphere the index of refraction is almost constant for the entire electromagnetic spectrum. When water vapor is added it can be shown that the dipole moment of the molecule tends to follow electric-field changes at microwave frequencies but not at optical frequencies; as a result, the microwave index of refraction is greater. Refractive effects vary widely with meteorological conditions, and for some abnormal cases the wave bends sharply downward (superrefraction), upward (subrefraction), or becomes trapped (ducting). A loss in signal due to refraction should be distinguished from attenuation by absorption or multiple scattering. In the latter case the energy is for all practical purposes lost, whereas in the former case the wave is only bent, thereby resulting in a change in angle of arrival at the antenna. This angle change can be compensated for, if known.

Total atmospheric attenuation. The effects of atmospheric gases, clouds, and precipitation on millimeter waves have been examined for a homogeneous medium. Those results can be applied to a horizontally stratified atmosphere and used to estimate total atmospheric attenuation as a function of meteorological conditions and location of the space terminal. Models of a standard atmosphere and an atmosphere with precipitation are shown in Figs. 6 and 7. Only the lower 20 km of the atmosphere are shown, as contributions from atmospheric water vapor and oxygen above that altitude are negligible at 15 and 35 GHz. For precipitation, only the lower 6 km are considered. In Fig. 8 the total atmospheric attenuation is plotted for dry, humid, and rainy conditions as a function of zenith angle at 15 and 35 GHz. Attenuation resulting from ice clouds is not included since it is relatively low. It can be seen that the total atmospheric attenuation, which is relatively low at angles near zenith, increases monotonically with zenith angle and becomes very large near the horizon. It is interesting to note that the amount of the lower atmosphere traversed ranges from 20 km near zenith to approximately 500 km along the horizon and for this reason it becomes quite apparent why attenuation at angles near the horizon is so large.

Atmospheric noise. Atmospheric gases and precipitation in addition to absorbing also emit electromagnetic energy; this emission is often referred to as sky noise. For a uniform medium in thermodynamic equilibrium, the theory of blackbody radiation states that a good absorber is also a good emitter (Kirchhoff's law). The atmosphere may be considered to approximate such a medium. Using Kirchhoff's law and the principle of conservation of energy, one can derive the radiative transfer equation,[7] which describes the radiation field in the atmosphere that absorbs, emits, and scatters energy. This field can be measured with an antenna, and for a nonscattering atmosphere the amount of radiation that is received when the antenna is pointed at a source is

$$T_a = T_a' e^{-\tau} + \int_0^\infty T(s)\gamma(s) \exp\left[-\int_0^s \gamma(s')\,ds'\right] ds \quad (2)$$

FIGURE 4. Attenuation vs. rainfall rate.[5]

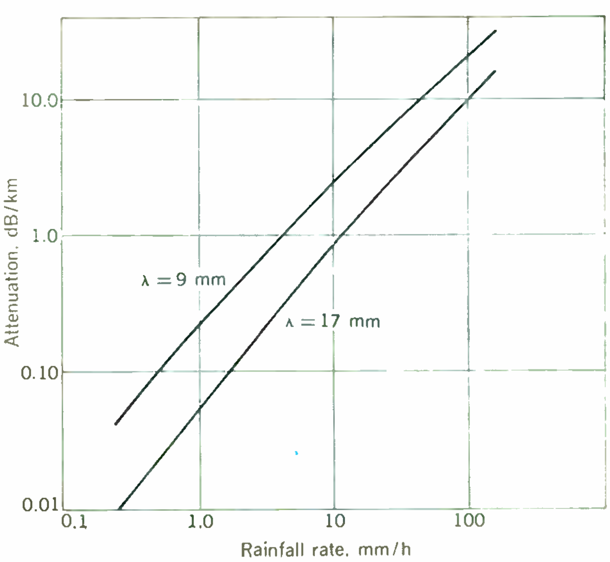
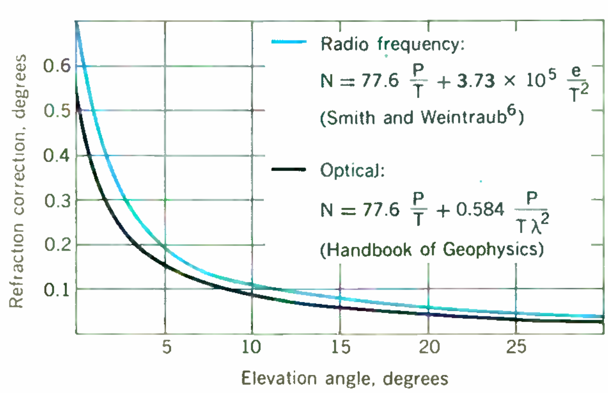


FIGURE 5. Refraction correction vs. elevation angle.



where

T_a = effective antenna temperature, °K
T_a' = effective antenna temperature with no intervening atmosphere, °K
τ = total attenuation, nepers
$\gamma(s)$ = absorption coefficient
s = distance from antenna (ray path)

Equation (2) can be explained as follows: The antenna temperature T_a is proportional to the power received by the antenna. It is equivalent in a sense to the temperature that a resistor would have if it were radiating the same amount of power as is received by the antenna within the same frequency band. The first term on the right side of this equation represents direct energy, from the source, that has been attenuated by the atmosphere, and the second term is the contribution resulting from noise radiated by the atmosphere. The intensity of this radiation is usually represented by an equivalent blackbody temperature and is referred to as the apparent sky temperature. Since the performance of a communications system is a function of signal-to-noise ratio, it is important to know the sky-noise contribution since it, along with the noise figure of the receiver, determines the total noise level of the overall system.

Attenuation measurements

In principle, there are two ways of determining atmospheric attenuation without having to use a space vehicle. In the first, attenuation may be measured by observing the extinction of an extraterrestrial source as a function of the zenith angle—that is, the first term on the right-hand side of Eq. (2). In the second method, the atmospheric emission—the second term of the right-hand side of Eq. (2)—is measured and the corresponding attenuation is calculated using an assumed atmospheric mean temperature.

Atmospheric attenuation using the sun as a source. The sun is the only extraterrestrial source suitable for attenuation measurements of wide dynamic range at millimeter wavelengths. Although the total disk temperature is fairly stable at these wavelengths, measurements made during a period of enhanced solar activity can lead to significant errors. For a plane earth, the path length through the troposphere is proportional to the secant of the zenith angle; if the atmosphere is horizontally stratified,

$$a(\phi) = a_0 \sec \phi \qquad (3)$$

where ϕ is the zenith angle and a_0 is the vertical attenuation in decibels. For the case of the spherical earth, the secant law is useful down to zenith angles of about 85 degrees. If we use Eq. (2), changing the units of attenuation (nepers to decibels), then under conditions in which the secant law holds, the antenna temperature $T_a(\phi)$, when the space vehicle is pointed at the sun, is given by

$$T_a(\phi) = T_a' \times 10^{-(a_0/10)\sec\phi} + T_s(\phi) \qquad (4)$$

where $T_s(\phi)$ is the apparent sky temperature. If $T_s(\phi)$ is balanced out or is negligible, Eq. (4) may be written

$$\log T_a(\phi) = -(a_0/10)\sec\phi + \log T_a' \qquad (5)$$

Thus if the logarithm of $T_a(\phi)$—or an equivalent number, such as an output meter deflection—is plotted against $\sec \phi$, the slope of the line is the zenith attenuation and the attenuation for other zenith angles may be obtained

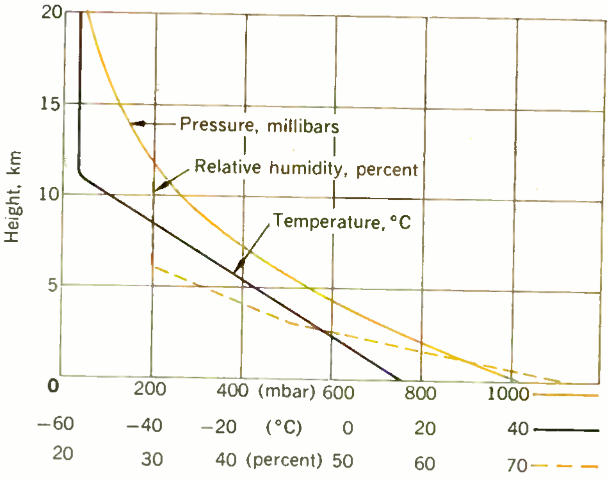


FIGURE 6. Model of standard atmosphere.

FIGURE 7. Model of atmosphere with precipitation.

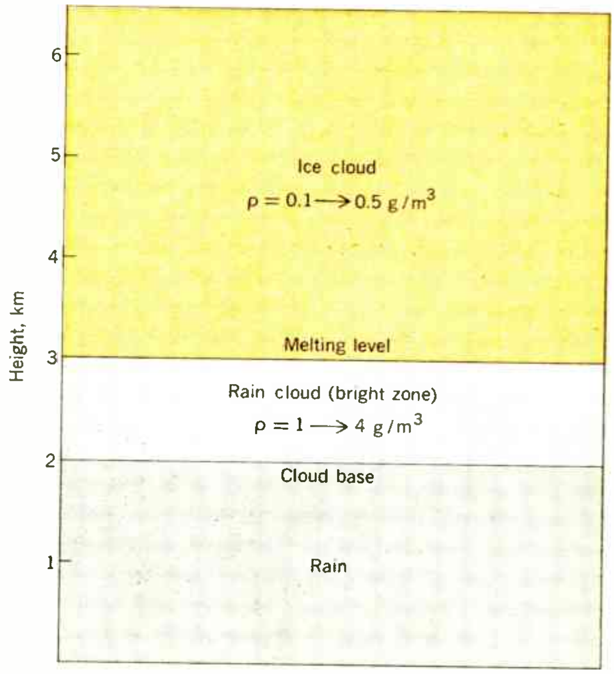
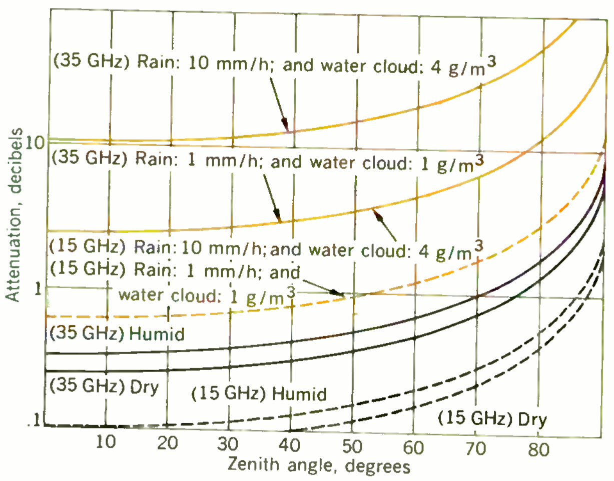


FIGURE 8. Total atmospheric attenuation at 15 GHz and 35 GHz (calculated).



by simply multiplying a_0 by the secant of the angle. Absolute attenuation measurements can thus be made without knowledge of the solar temperature or antenna gain. If measurements are to be made under weather conditions that invalidate the secant law, a means must be provided to set the system gain to a predetermined level.

Measurements at 15 and 35 GHz were made daily from mid-January to mid-July 1966, at the Air Force Cambridge Research Laboratories' Prospect Hill Radio Observatory in Waltham, Mass., at an elevation of 480 feet (150 meters). Conventional comparison-load radiometers were used; the outputs were displayed on meters scaled from 0 to 100, and prior to each measurement system gains were adjusted so that full-scale readings would be obtained if the antennas were pointed at the sun with no intervening atmosphere. As the sun entered the antenna beams, the antennas were scanned over a small azimuth angle to account for pointing errors, caused chiefly by refractive effects. Peak readings of the meters then gave the percentage transmission of the atmosphere at the two frequencies directly.

The calibration was done as follows: At the start of the program the attenuations at solar transit were estimated from sky-temperature measurements; at transit, the antennas were directed at the sun and the system gains adjusted to give the appropriate meter readings. The antennas were then swung off the sun, and noise sources coupled into the antenna transmission lines were turned on. The resulting meter deflections were then used as calibrations for measurements immediately following. Plots of the logarithms of the meter deflections versus secant ϕ were made for each series of measurements under conditions of clear sky or thin clouds. The plots provided a convenient method for calibration correction since from Eq. (5) it is seen that the intercept at secant $\phi = 0$ is $\log T_a'$. Failure to intercept at $\log T_a = 2$ (corresponding to a meter deflection of 100) indicated improper gain for the series of measurements. In this case corrected data were obtained by adjusting the line for proper intercept and taking the attenuations for the various angles directly from the plot. Under sky conditions that did not permit a secant plot, calibration errors would go undetected.

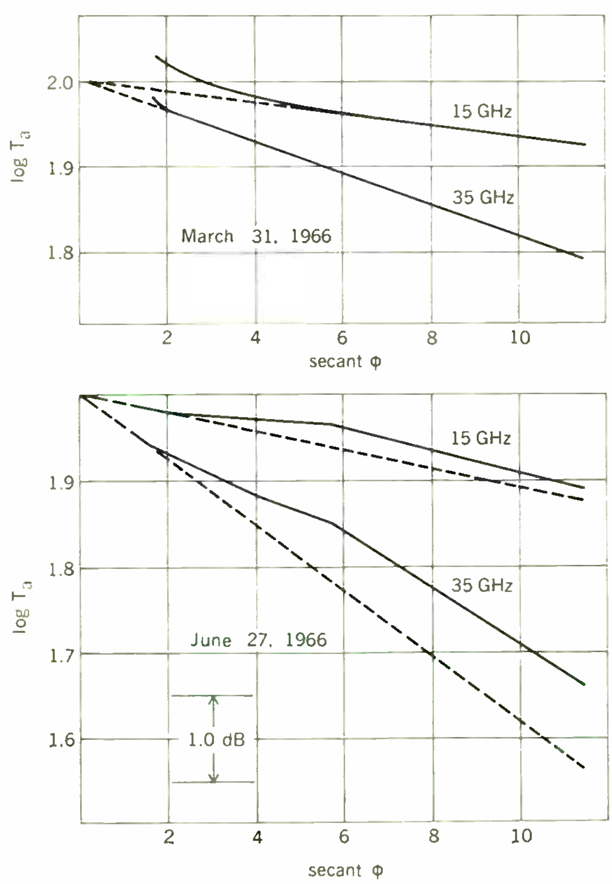
The chief source of errors in the measurement program was variations in solar flux. These variations result from two effects: (1) the slow variation in apparent solar diameter due to the elliptic orbit of the earth, and (2) disturbed solar conditions. The former effect poses no problem, since it is predictable. The latter may be a slowly varying effect, lasting for days, or a burst, lasting for minutes or hours. Approximately 20 percent of the secant plots indicated possible flux enhancements, which, with two exceptions, could lead to measurement errors of about 0.2 dB maximum. The effects of the two most significant events observed are shown on the secant plots for March 31 and June 27, 1966 (Fig. 9). The effect of the burst on March 31 lasted for about 3 hours at 15 GHz with an initial flux increase of about 10 percent. The lesser effect at 35 GHz was attributable, at least in part, to cloud cover during the first two measurements. In contrast, the plot for June 27 shows a rather slow increase in flux, with a greater effect at 35 GHz. The flux enhancement lasted throughout the following day, but at a considerably reduced level.

Measured attenuations at the two frequencies as a function of zenith angle under various meteorological conditions are shown in Fig. 10. The values T_g and ρ refer to the average surface temperature and absolute humidity during the measurement period. The two lowest curves in each of the figures are typical for warm, humid days and for cold, dry days under conditions of clear sky or cirrus clouds. Attenuation on clear summer days is caused principally by water vapor, and since there were wide fluctuations in absolute humidity during this period, considerable variations in day-to-day attenuations were observed. This is in contrast to winter days, when the water-vapor content is so low that oxygen absorption becomes predominant, and clear-sky attenuations were quite stable with time. The upper curves in Fig. 10 indicate the large and rapid variations in attenuation that result under conditions of variable cloud cover and sporadic rain.

Attenuation from cirrus clouds was not measurable at either frequency. Attenuation produced by large fair-weather cumulus clouds at a zenith angle of 45 degrees ranged from about 0.1 to 0.5 dB at 35 GHz; the maximum observed at 15 GHz was approximately 0.15 dB.

Percentage of time distributions for 15 and 35 GHz at various antenna zenith angles are shown in Fig. 11, each curve representing 125 samples. Although the data were acquired over a 6-month period only, they should be quite representative for the full year. Temperatures were approximately normal over the period; precipitation, however, was about 18 percent below normal, so the data are somewhat optimistic. It should also be noted that heavy rainfall was not encountered during any of the scheduled measurements. The curves for $\phi = 0$ degrees

FIGURE 9. Secant plots showing flux enhancement.



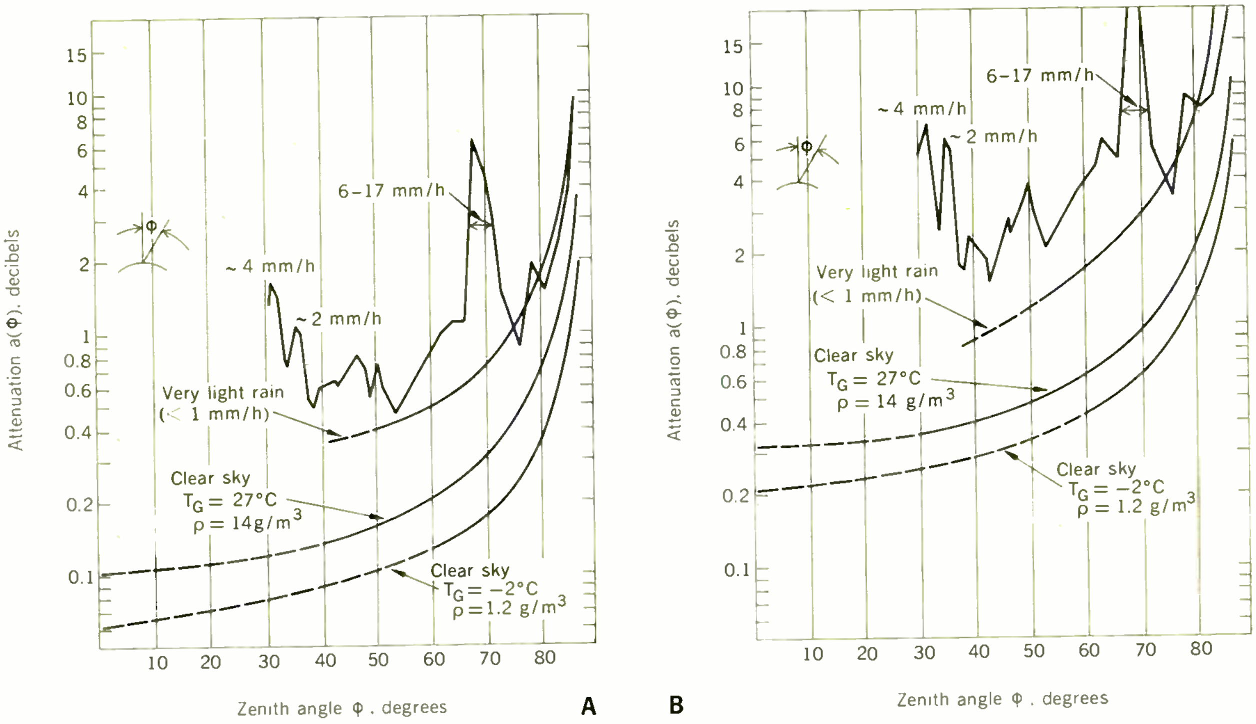
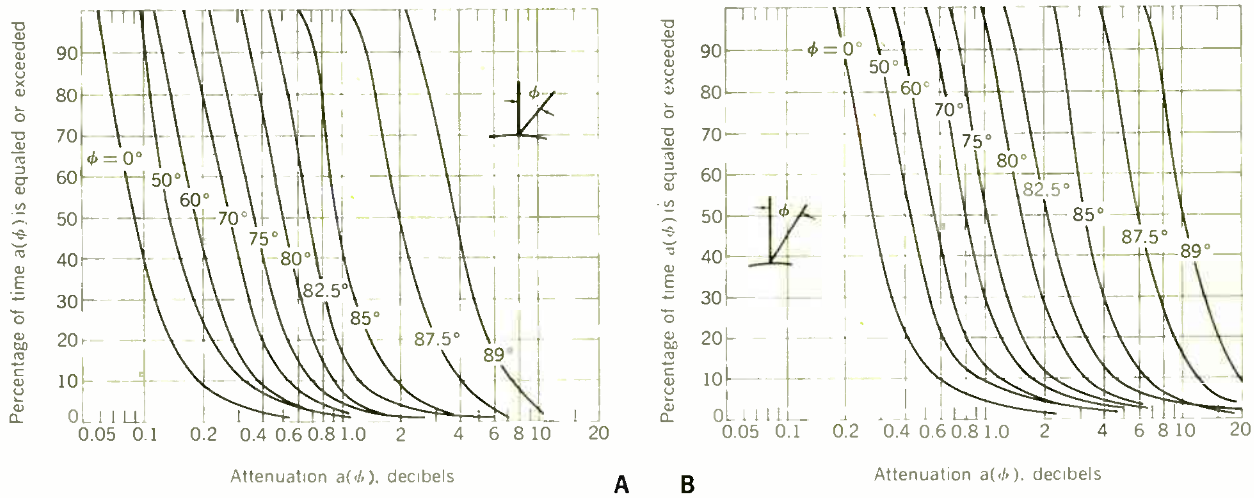


FIGURE 10. Total atmospheric attenuation at (A) 15 GHz and (B) 35 GHz.[11]

FIGURE 11. Total atmospheric attenuation distributions at (A) 15 GHz and (B) 35 GHz.[11]



were obtained by halving the data for ϕ = 60 degrees; it was also necessary to extrapolate some of the data for ϕ = 50 and 60 degrees, since the sun did not reach these angles in the early part of the program.

The data shown are, of course, applicable only to locations having a climate comparable to that of the Boston area. Extrapolation of the data to other geographic areas is difficult because it involves meteorological statistics. Two important considerations are the elevation and latitude of the location, since the mean annual precipitable water is essentially a function of these factors only, increasing as the latitude decreases and being approximately inversely proportional to elevation.[8] Since the oxygen density also decreases with increased altitude, the total attenuation falls off rapidly, as indicated in Fig. 12, which was computed for a zenith angle of 85 degrees for a typical summer day.

To determine any possible correlation of attenuation with surface pressure, temperature, and absolute humidity, scatter plots were made of the vertical attenuations obtained from all secant plots against the three parameters. From these plots it was found that for clear-sky conditions, absolute humidity is the predominant effect, the correlation being evident from Fig. 13. The equations of best straight-line fit for zenith attenuation based on these data are

$$a_0 = 0.055 + 0.004\rho \quad \text{(15 GHz)} \qquad (6)$$

$$a_0 = 0.17 + 0.013\rho \quad \text{(35 GHz)} \qquad (7)$$

Correlation with surface temperature was considerably

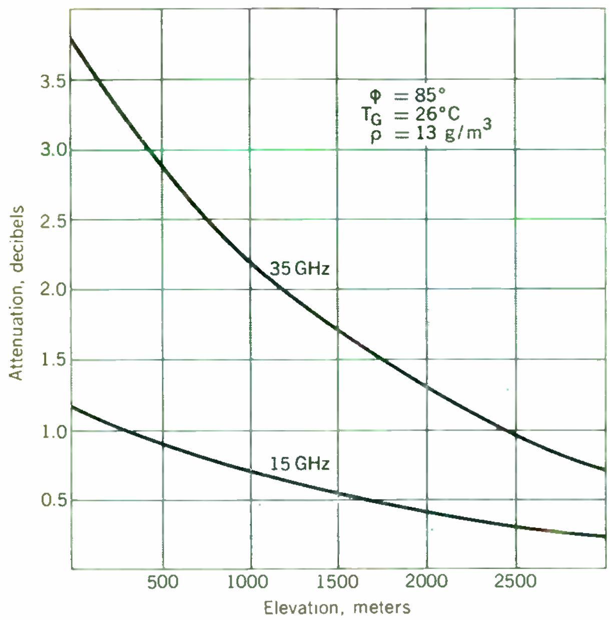
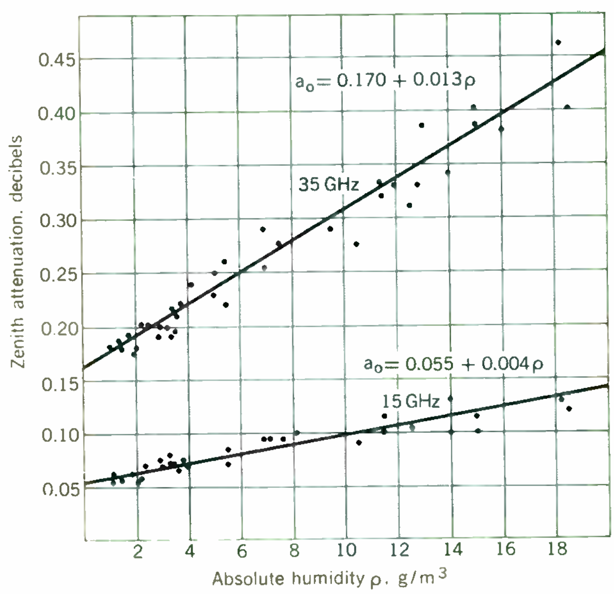


FIGURE 12. Total atmospheric attenuation vs. elevation.

FIGURE 13. Zenith atmospheric attenuation as a function of absolute humidity.



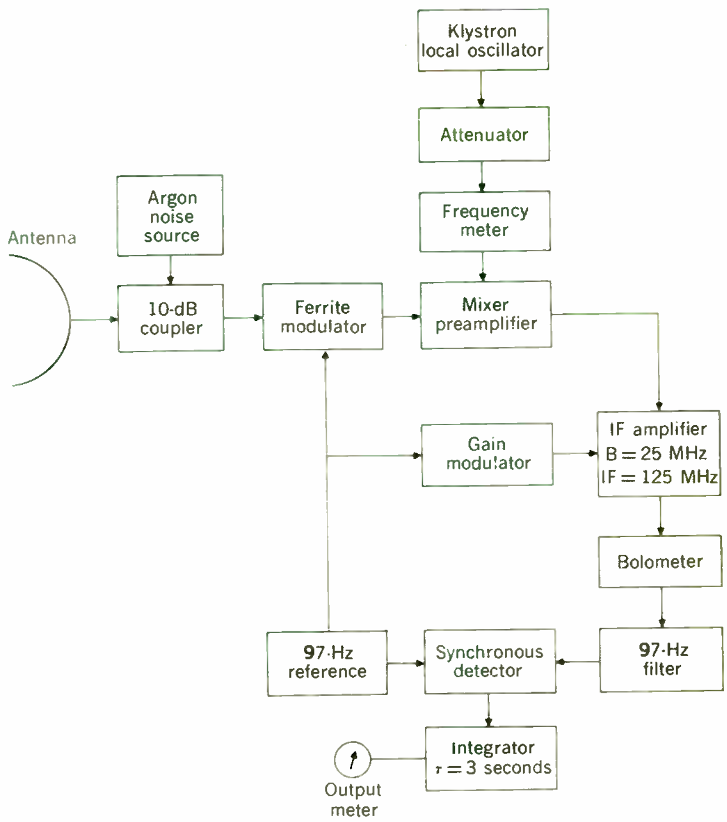


FIGURE 14. Block diagram of radiometer.

lower; the general increase of attenuation with temperature can be related to the absolute humidity, which in general increases with temperature. The only correlation with pressure was a tendency toward lower attenuations at the higher pressures. This also can be related to the absolute humidity, which is at a minimum in the winter months, the period associated with higher pressures.

The basic circuits of the two radiometric systems were identical; a block diagram is shown in Fig. 14. The ferrite modulator acts as a single-pole single-throw switch operating at 97 Hz. The noise temperature at the mixer input is thus the antenna temperature with the switch in the on position, and ambient in the off position. The argon noise source coupled into the switch was used for system gain calibration. Bolometers were used as second detectors to insure square-law response over a wide dynamic range. The measurement technique required that the radiometer input be at a noise balance prior to each measurement—that is, the condition of equal antenna and comparison (ambient) temperatures. This was done by square-wave-modulating the gain of the IF amplifier in synchronism with the RF switching frequency, the amplitude of the modulation being continuously variable. The radiometer front ends were housed in weathertight boxes located directly behind the antennas; controls and output indicators were located in the antenna control console.

The parabolic antennas were mounted on a Nike Ajax mount, as shown in Fig. 15. The half-power beamwidths were 0.9 degree for the 5-foot (1.5-meter) antenna used at 15 GHz and 0.75 degree for the 3-foot (0.9-meter) 35-GHz antenna.

Atmospheric attenuation from an emission measurement. Under conditions in which atmospheric attenuation is caused by absorption only, the total attenuation τ and the emission temperature T_s are related by the expression

$$1 - e^{-\tau} = \frac{T_s}{T_m} \tag{8}$$

where T_m is the mean temperature of the atmosphere averaged over the absorption along the ray path.[9] Since the attenuation per unit distance decreases exponentially with altitude, T_m approaches the surface temperature of the earth and normally falls in the range of 250–290°K. Under clear-sky conditions T_s is typically only a small

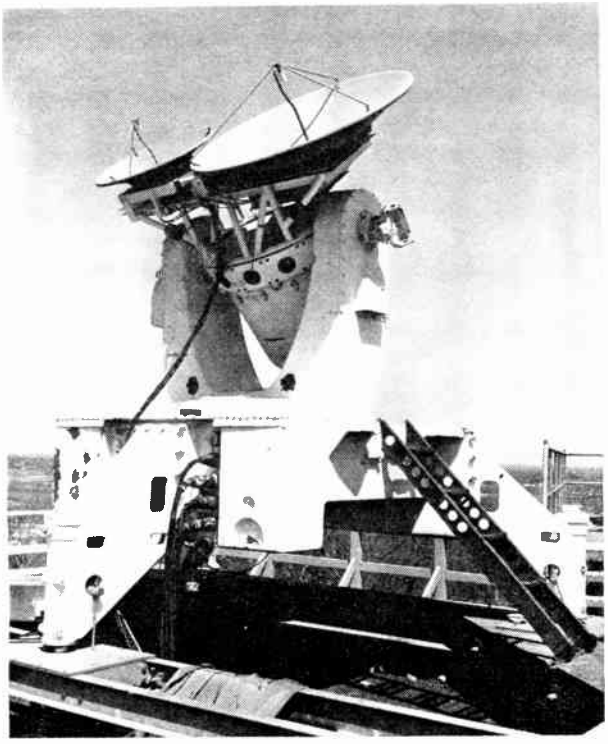


FIGURE 15. View of antennas and radiometer front ends.

fraction of T_m, so it is possible to compute the attenuation quite accurately from the measured emission temperature and an estimated value of T_m. Under conditions of heavy clouds or precipitation (for which there is appreciable scattering), T_s may approach the value of T_m, which is in turn more difficult to estimate. Thus a significant error in the computed attenuation may result.

Simultaneous measurements of atmospheric attenuation and emission were conducted at 15 and 35 GHz during the period from November 1966 through April 1967.[10] The attenuation measurements were made with the equipment shown in Fig. 14. The radiometers for emission measurements were similar to those used for the attenuation measurements with the exception that pyramidal horns were used in place of paraboloidal antennas.[11] Using a model atmosphere, T_m was computed for various values of surface temperature and humidity; the results showed that T_m varies directly with surface temperature and is only moderately dependent on humidity. For the atmospheric model and line-width constants used, the following relation holds:

$$T_m = 1.12T_g - 50 \quad (9)$$

where T_g is the surface temperature in degrees Kelvin. Using Eqs. (8) and (9), atmospheric attenuations were calculated from the emission measurements and compared with the values obtained using the sun as a source. Under clear-sky conditions, the results were in close agreement. Under other conditions, however, the agreement was rather poor, which may be attributed to the reasons stated previously. Although there are advantages in determining atmospheric attenuation from emission measurements, in the sense that the measurements can be made at any time of day or night and also at many angles in a short period of time, it should be emphasized that this method should be limited to clear-sky conditions.

Conclusions

The major obstacle in utilizing millimeter waves to relieve spectrum congestion is attenuation by the lower atmosphere. From the data presented here it is evident that in selected portions of the band the attenuation is sufficiently low to permit wide-band earth-to-satellite communications with moderate reliability. If a requirement for very high reliability is to be met, however, a means must be found to combat the high attenuation due to heavy rainfall. It has been shown that atmospheric attenuation decreases with both increasing altitude and decreasing humidity. Therefore, locating the earth terminal at a high elevation in a dry climate could solve the problem; this approach, however, may not be practical because of economic considerations. Since heavy rainfall is usually quite localized, there is also the possibility of improving system reliability through space diversity—that is, through the use of two or more terminals spaced sufficiently far apart that the probability of heavy rain occurring at all terminals is very low. A full evaluation of this approach, which is under active study, will require a greatly expanded knowledge of the distribution of rain in both space and time. Information on rainfall attenuation is also very limited. One program to obtain such information is under way at Hilo, Hawaii, where measurements are made at 15 and 35 GHz, using the sun as a source. This area was selected because it rains on an average of 300 days a year, with very high annual accumulations, thus making it possible to conduct many measurements for varying rainfall rates.

These measurements do not provide information as to what limitations the atmosphere will impose on usable, or coherent, bandwidths. A program for obtaining this type of data, which requires a satellite-borne coherent source, is planned for 1969.[12]

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Short courses in electrical and electronics engineering—Fall 1968

An IEEE continuing education service

With this issue of IEEE SPECTRUM, the Institute is inaugurating a new service for its members—the gathering together and publishing of information on continuing education courses to be offered by universities in the schedule period immediately following publication. It is intended that the listing of these opportunities will be repeated perhaps three times a year—fall, spring, and summer.

To get the series started as soon as possible we are including in this initial listing continuing education courses scheduled for the late summer and fall of 1968 and for which information was available prior to the copy deadline for this issue of SPECTRUM. For further convenience in use, the list has been assembled by Region of university location and by topical subdivision of the field of electrical engineering.

Readers' comments on this new Institute service will be welcomed by the undersigned or by J. M. Kinn, IEEE's Director of Educational Services. In particular, we solicit your views on how this service can be made most useful to IEEE members.

J. N. Shive
Chairman
Educational Activities Board

Course	Date	Location	Fee	Contact
		REGION I		
Automatic control				
Introduction to Modern Control Theory and Its Applications	Aug. 5–16	Cambridge, Mass.	$400	M.I.T., Rm. E19-356, Cambridge, Mass. 02139
Computer				
Analog Simulation on a Digital Computer	Aug. 5–7	Brooklyn, N.Y.	$105	Polytechnic Institute of Brooklyn, Office of Special Programs, 333 Jay Street, Brooklyn, N.Y. 11201
Computer Application in Mechanical Engineering Design	November, one-day seminar	Orono and Portland, Maine	...	University of Maine, Office of State Technical Services, 109 Boardman Hall, Orono, Maine 04473
Computer Graphics	Sept. 16–18	Brooklyn	$105	Polytechnic Institute of Brooklyn, Office of Special Programs, 333 Jay Street, Brooklyn, N.Y. 11201
Computer Simulation II	Aug. 19–23	Brooklyn	$175	Polytechnic Institute of Brooklyn, Office of Special Programs, 333 Jay Street, Brooklyn, N.Y. 11201
PL/1 Programming	Aug. 12–14	Brooklyn	$105	Polytechnic Institute of Brooklyn, Office of Special Programs, 333 Jay Street, Brooklyn, N.Y. 11201
Problem Oriented Computer Workshop	Aug. 26–30	Brooklyn	$175	Polytechnic Institute of Brooklyn, Office of Special Programs, 333 Jay Street, Brooklyn, N.Y. 11201

Course	Date	Location	Fee	Contact
		REGION I (continued)		
Special-Purpose, Time-Shared On-Line Information Systems	Aug. 5–7	Brooklyn, N. Y.	$105	Polytechnic Institute of Brooklyn, Office of Special Programs, 333 Jay Street, Brooklyn, N.Y. 11201
Engineering writing and speech				
Communication Technical Information	Aug. 5–9	Cambridge, Mass.	$250	M.I.T., Rm. E19-356, Cambridge, Mass. 02139
General interest				
Applied Heat Transfer	Aug. 5–8	Brooklyn	$140	Polytechnic Institute of Brooklyn, Office of Special Programs (see above)
Discrete Time Systems and Digital Filtering	Aug. 19–23	Brooklyn	$175	Polytechnic Institute of Brooklyn, Office of Special Programs (see above)
Engineering Systems Analysis	Aug. 12–23	Cambridge	$500	M.I.T., Rm. E19-356, Cambridge, Mass. 02139
Examination of Analysis of Variance	Aug. 14–15	Brooklyn	$ 70	Polytechnic Institute of Brooklyn, Office of Special Programs (see above)
Examination of Nonparametric Tests	Aug. 28–29	Brooklyn	$ 70	Polytechnic Institute of Brooklyn, Office of Special Programs (see above)
Forecasting with Econometric Models	Aug. 12–23	Cambridge	$400	M.I.T., Rm. E19-356, Cambridge, Mass. 02139
Image Processing: Basic Techniques and Applications	Aug. 5–16	Cambridge	$400	M.I.T., Rm. E19-356, Cambridge, Mass. 02139
Information Display Systems	Aug. 26–30	Brooklyn	$225	Polytechnic Institute of Brooklyn, Office of Special Programs (see above)
Information Technology	Aug. 19–30	Cambridge	$400	M.I.T., Rm. E19-356, Cambridge, Mass. 02139
Introduction to Modern Control Theory and Its Applications	Aug. 5–16	Cambridge	$400	M.I.T., Rm. E19-356, Cambridge, Mass. 02139
Modern Engineering Program	Fall 1968 15 meetings	Brooklyn	$325	Polytechnic Institute of Brooklyn, Dean of Special Programs (see above)
		REGION II		
Audio and electroacoustics				
Acoustics and Noise Control in Buildings	Sept. 9–13	University Park, Pa.	...	Conference Center—Continuing Education, J. Orvis Keller Building, The Pennsylvania State University, University Park, Pa. 16802
Automatic control				
Modern Control Theory and Applications	Aug. 19–30	Columbus, Ohio	$275	The Ohio State University, Engineering Short Courses, 2070 Neil Avenue, Columbus, Ohio 43210
Reliability				
Reliability Engineering Seminar	Aug. 19–23	University Park	...	Conference Center—Continuing Education, J. Orvis Keller Building, The Pennsylvania State University, University Park, Pa. 16802
General interest				
One-Week Advanced Course	Aug. 12–16	Columbus	$175	The Ohio State University, Engineering Short Courses, 2070 Neil Avenue, Columbus, Ohio 43210

Course	Date	Location	Fee	Contact
		REGION III		
Computer				
Functional Analysis and Numerical Methods	Sept. 8–20	Atlanta, Ga.	$300	Director, Department of Continuing Education (A), Georgia Institute of Technology, Atlanta, Ga. 30332
Geoscience electronics				
Theory of Land and Engineering Surveys	Oct. 14–18	Atlanta	$150	Director, Department of Continuing Education (A) (see above)
Nuclear science				
Nuclear Engineering Fundamentals	Nov. 4–15	Atlanta	$300	Director, Department of Continuing Education (A) (see above)
		REGION IV		
Computer				
Computer Applications in Structural Engineering	Aug. 19–23	Madison, Wis.	$150	Summer Short Courses, Department of Engineering, University Extension, The University of Wisconsin, 432 North Lake Street, Madison, Wis. 53706
Computer Simulation Methods	Aug. 19–23	Madison	$150	Summer Short Courses, Department of Engineering, University Extension, The University of Wisconsin, 432 North Lake Street, Madison, Wis. 53706
Short Course in Digital Process Control System	Sept. 16–25	Lafayette, Ind.	$250	Business Office—U.E.A., 110 Memorial Center, Purdue University, Lafayette, Ind. 47907
Microwave theory and techniques				
Microwave Semiconductor Devices and Circuits (Fundamentals)	Aug. 5–9	Ann Arbor, Mich.	$200	Engineering Summer Conferences, Chrysler Center, North Campus, The University of Michigan, Ann Arbor, Mich. 48105
Microwave Semiconductor Devices and Circuits (Advanced Concepts)	Aug 12–16	Ann Arbor	$200	Engineering Summer Conferences, Chrysler Center, North Campus, The University of Michigan, Ann Arbor, Mich. 48105
General interest				
Computers and Modern Process Control—A Course for Engineering and Production Managers	Sept. 30–Oct. 4	Lafayette	$150	Business Office—U.E.A., 110 Memorial Center, Purdue University, Lafayette, Ind. 47907
Modeling of Industrial Processes for Computer Control	Oct. 14-23	Lafayette	$250	Business Office—U.E.A. (see above)
Short Course in Process Dynamics and Control	Oct. 28–Nov. 2	Lafayette	$150	Business Office—U.E.A. (see above)
		REGION V		
Automatic control				
Optimization Techniques: Theory and Practice	Aug. 19–30	Austin, Tex.	$350	Engineering Institutes of the College of Engineering, c/o Division of Extension, The University of Texas at Austin, Austin, Tex. 79712

Course	Date	Location	Fee	Contact
REGION V (continued)				
Current Trends in Automatic Control Theory	Aug. 19–24	St. Louis, Mo.	. . .	Institute for Continuing Education in Engineering and Applied Science, Washington University, Box 1048, St. Louis, Mo. 63130
Circuit theory				
Computer-Aided Circuit Analysis and Design (two weeks of laboratory and lecture workshops)	Sept. 5–9 Sept. 12–16	Columbia, Mo.	$150 per week	College of Engineering, University Computer Center, Extension Division, University of Missouri, Columbia, Mo.
Electron devices				
Principles of Semiconductor Devices	Aug. 19–23	Boulder, Colo.	$200	G. J. Maler, Associate Dean, College of Engineering, University of Colorado, Boulder, Colo. 80302
Geoscience electronics				
Design and Construction for Deep Sea Exploration	Nov. 11–15	St. Louis	. . .	Institute for Continuing Education in Engineering and Applied Science, Washington University, Box 1048, St. Louis, Mo. 63130
Digital Processing of Gravity and Magnetic Data	Aug. 8–16	Rolla, Mo.	. . .	Dwight Hafeli, Extension Division, University of Missouri, Rolla, Mo. 65401
Symposium on Use of Computers in Hydrology	Dec. 8–14	Tucson, Ariz.	. . .	B. H. Pochyla, Director, Continuing Education, The University of Arizona, Tucson, Ariz. 85721
Well Log Analysis for Formation Evaluation Part 1—Fundamental Applications	Dec. 2–13	Austin, Tex.	$400	Engineering Institutes of the College of Engineering, c/o Division of Extension, The University of Texas at Austin, Austin, Tex. 78712
Industrial electronics and control instrumentation				
Process Measurement and Control System Design	Sept. 3–14	Austin	$350	Engineering Institutes of the College of Engineering (see above)
Power				
Power Distribution Conference	Oct. 21–23	Austin	$ 10	Engineering Institutes of the College of Engineering (see above)
Concepts of Modern Power Engineering	Oct. 21–Nov. 1	St. Louis, Mo.	. . .	Institute for Continuing Education in Engineering and Applied Science, Washington University, Box 1048, St. Louis, Mo. 63130
Reliability				
Sixth Annual Reliability Engineering and Management Institute	Nov. 4–13	Tucson, Ariz.	. . .	B. H. Pochyla, Director, Continuing Education, The University of Arizona, Tucson, Ariz. 85721
Workshop on Reliability and Maintainability Technology	Aug. 14–17	St. Louis	. . .	Institute for Continuing Education in Engineering and Applied Science, Washington University, Box 1048, St. Louis, Mo. 63130
General interest				
Computer Control of Processes	Aug. 19–23	Boulder, Colo.	$200	G. J. Maler, Associate Dean, College of Engineering, University of Colorado, Boulder, Colo. 80302
REGION VI				
Power				
Mathematics, Computer Programming, and Analytical Techniques for Electric Power Networks	Aug. 5–23 3 one-week courses	Santa Clara, Calif.	1 week: $175 2 weeks: $300 3 weeks: $400	Prof. J. A. Peterson, School of Engineering, University of Santa Clara, Santa Clara, Calif. 95053

X radiation from color television receivers

During a recent conference, the basis for a common understanding of definitions and measurement procedures in determining the extent of a potential hazard was outlined. Whether this groundwork will lead to a final solution still remains unsettled!

Marcelino Eleccion *Assistant Editor*

When black-and-white television receivers using cathode-ray tubes were introduced to the consumer public, measurements verified that, with the voltages and currents needed for satisfactory pictures, the externally emitted X radiation was indeed negligible. Color receivers, with much higher voltages and currents, led to a re-examination of the problem. Again, it was found that proper design could produce a bright picture with negligible radiation. In the past two years, however, some unusual events, reported experiments, and surveys involving color receivers have been widely publicized in the lay press—resulting in a major controversy with respect to the existence of radiation hazards. In an effort to free the subject from political overtones and from what has appeared to some as "sensational journalism," the National Center for Radiological Health joined the Electronic Industries Association in sponsoring a special measurements conference, reported herein, which represents a first step toward complete examination of the X-radiation problem.

". . . it is quite clear that the probability of significant or even detectable medical effects from X rays emitted by faulty TV receivers is vanishingly small." Victor P. Bond, M.D., Ph.D., associate director, Brookhaven National Laboratory, and chairman, Radiation Bio-Effects Advisory Committee of NCRH, *Television Digest*, February 26, 1968.

"Public Health Official Says 5% of Color Sets Apparently Represent a Health Hazard"—headline from *Wall Street Journal*, April 1, 1968.

These two quotations indicate the degree of controversy that has arisen over X radiation from color television receivers during the last few years. With the public's concern naturally aroused by the growing and often conflicting publicity afforded the controversy, the time seemed ripe for an evaluation of the measurement techniques to be used in appraising the situation.

On March 28 and 29, 1968, a Conference on Detection and Measurement of X Radiation from Color Television Receivers was held in Washington, D.C., by the Public Health Service's National Center for Radiological Health (NCRH) in cooperation with the Electronic Industries Association (EIA). The meeting, summarizing more than a year of collaboration between the two organizations on the subject, clarified many of the basic issues involved.

In the words of the welcoming speaker, James G. Terrill, Jr., the director of NCRH, "it became apparent that there was a need to establish some kind of forum at which the rapidly accumulating information on instrumentation needs and limitations, which was being collected both by industry and by the Government, could be presented and discussed."

After a short keynote address by Robert W. Galvin, who is both president of the EIA and chairman of the

1959 NCRP Statement on Radiation from Television Receivers

At its meeting in November 1959, the Executive Committee of the NCRP agreed that a statement should be made with regard to the maximum permissible dose from television receivers. Such a statement has been prepared and voted upon by the full committee.

The following position has been adopted by the NCRP:

During the past years members of the NCRP have investigated the emission of x rays from television receivers. From a genetic point of view even sources of minute radiation are of significance if they affect a large number of people. X rays emitted by home television sets are, therefore, of interest because of the high percentage of the population involved. In order to insure that the television contribution to the population gonad dose will be only a small fraction of that due to natural background radiation, the NCRP recommends that the exposure dose rate at any readily accessible point 5 cm. from the surface of any home television receiver shall not exceed 0.5 mr per hour under normal operating conditions.

Laboratory and field measurements [1] have shown that with this maximum permissible exposure level the television contribution to the gonad dose at the usual viewing distances will be considerably less than 5 per cent of that due to the average natural background radiation. Most of the present television receivers already meet this requirement with a high factor of safety. In general, therefore, no changes in shielding of existing sets will be required. However, the recommended limit will insure that future television receivers, operating at higher voltages, will not contribute significantly to the population gonad dose.

[1] Braestrup, C. B., and Mooney, R. T.: *X-ray Emission from Television Sets*, Science 130, 1071-1074, Oct. 23, 1959.

board of the Motorola Corporation, 28 speakers presented their technical papers in four sessions distributed over two days, with eight liberal discussion periods providing the necessary opportunity for assimilating and exchanging ideas. A final session, comprised of panelists J. G. Terrill, Jr., and D. J. Nelson of NCRH, N. W. Aram and J. L. Sheldon of EIA, and Paul C. Tompkins, executive director of the Federal Radiation Council, served to underline the goals of the conference, help clarify particular issues, and project ideas for continuing the investigation of X radiation.

Any investigation concerning the detection and measurement of X radiation from television receivers must consider the November 1959 statement on X-ray protection standards for home television receivers that was issued by the National Committee on Radiation Protection and Measurements (NCRP),* since government and industry standards are based upon it (see tinted box above). The basic intent of that statement was reaffirmed by the NCRP on February 23 of this year,[1] and can be said to be met "if the exposure rate, averaged over an area of 10 square centimeters, does not exceed the stated 0.5 milliroentgens in an hour at any external location 5 cm from the surface of the television receiver cabinet" under normal operating conditions. A description of the evolution and status of the 1959 recommendation was contained in the first two papers of Session II.

The NCRP statement of 1959 was well thought out and has not been attacked. It was based on a simple consideration: that man is always exposed to radiation from cosmic rays and radioactive elements in the earth and other materials anyway. This background radiation is from 0.01 to 0.02 mR/h; hence, at a 2.3-meter viewing distance, the NCRP limit is below the background level. Since radiation effects on man are (at least partially) cumulative, the NCRP limit was estimated to give a cumulative effect of *less than 5 percent of background radiation* with 1000 hours of viewing time per year (nearly 3 hours per day).[2]

It appears, therefore, that the controversy is based upon a radiation level that was conservative to begin with; and that the sensational headlines that have been appearing recently are unwarranted. Let's look at the full story.

History

An understanding of the events and conditions leading up to the present conference should be realized if one is to fully appreciate the significance of the results.

According to *Van Nostrand's Scientific Encyclopedia* (3rd edition), it has been found "that X rays arise wherever cathode rays encounter solids; that 'targets' of high atomic weight yield more copious X rays; and that the greater the speed of the cathode particles, the more penetrating, or the 'harder' the X rays are."

Since the modern television receiver requires a high-voltage rectifier and cathode-ray tube, the inference that X radiation might be emitted at harmful levels during the course of normal operation naturally became the subject of several investigations.[2–6] However, Braestrup and Mooney (of the Physics Laboratory at Francis Delafield hospital in New York), in their 1959 report,[2] observed that, on the basis of their laboratory and field measurements with voltages up to 25 kV, "the possibility of somatic radiation injuries to the viewer from conventional television sets is extremely remote." Indeed, they discovered that "only a minute fraction of the emitted radiation is transmitted through the glass panel" at the front of the television tube.†

Genetically, a radiation level of 0.5 mR/h at 5 cm appeared "reasonable" to them, and even at this rate, "the gonad dose at usual viewing distances would still be less than 5 percent of that due to the average natural background radiation."

The question seemed settled until, in August 1966, Dr. John Nash Ott, chairman of an organization known as the Environmental Health and Light Research Institute of Sarasota, Fla., stirred up a controversy by announcing that he had acquired data affirming brain-damaging effects of television emissions. His concern arose from learning of reports that children became lethargic after viewing television for many hours. Suspecting X rays to be the source of the condition, he conducted experiments with rats exposed to the radiation of television sets. As a result, a few rats died, and Dr. Ott attributed the cause to brain damage from X rays.[7] Since the results of his experiments are not known to have been published, it has not been possible to make an objective appraisal of these reported results.

* Now the National Council on Radiation Protection and Measurements (NCRP), a nonprofit corporation chartered by the United States Congress in 1964.

† Three results of this study are worth noting, for they are repeated throughout the present conference:
1. "Radiation measurements on television sets... have very little meaning unless the tube voltage has been very accurately established and maintained."
2. "Between 8 and 10 cm, the reduction [in radiation level] is considerably less than is indicated by the inverse-square law."
3. "Even minute variations in the amount of materials of high atomic number present in the glass [panel] cause great changes in the attenuation coefficient."

Upon examination of histological specimen slides and photographs provided by Dr. Ott to the National Institute of Neurological Diseases and Blindness, staff members failed to corroborate his findings (see Ref. 8, p. 19).

Further experiments by Dr. T. S. Harvey involving white rats placed within 25 cm of color television receivers and accumulating 240 times the average dosage of a viewer watching for 1000 hours at 100 cm, have indicated that all rats "developed normally and produced normal offspring whose behavior and anatomy were normal."[9]

Perhaps anticipating the need for more rapid testing procedures, the NCRH began to develop measurement techniques for determining radiation exposure levels from television receivers in the fall of 1966.* In the course of this research, the few color sets that were tested met the existing standards. At about this time, consultation with the Federal Communications Commission, National Bureau of Standards, National Institutes of Health, EIA, National Association of Broadcasters, and the separate military services and various universities produced negative reports concerning excessive emission from television receivers.

This might well have ended the matter except for the occurrence of a most unexpected event. In December 1966, the New York State Department of Labor was informed by the General Electric Company "that the company had found excessive radiation fields being emitted by color television receivers on a production line." On May 11, 1967, at a meeting between NCRH staff and GE representatives in New York City, GE advised NCRH that it had started a corrective program to recall stocks of certain errant voltage-regulator tubes and to remedy over 110 thousand sets already in the possession of dealers and customers. By August 9, 1967, 98.3 percent of these sets had been corrected (see Ref. 8, pp. 20–21).

General Electric's finding was given great publicity in the lay press, which, rather than stressing the company's responsibility over the discovery, appeared to the television industry to alarm the public unduly. Additional publicity was created by congressional hearings such as those on electronic products radiation control conducted by the House Subcommittee on Public Health and Welfare during 1967.[8]

Following the GE disclosure, the Pinellas County Health Department, St. Petersburg, Fla., engaged in an initial home pilot survey of 164 "company X" color receivers at the request of NCRH. This first study showed that 32 percent of the receivers emitted radiation from the side or rear of the set in excess of the NCRP standard—chiefly from the rectifier or regulator tube. All emis-

* One recent example of these studies is contained in a paper published by Rechen *et al.*[10]

I. Pinellas County, Florida, Health Department survey of 20 brands of color television receivers

Net Exposure Rate, mR/h	Number of Receivers	Percent of Total (approx.)	Excessive Emitters, percent
Background	102	68.5	—
0.02–0.5	24	16.1	—
0.5–1.0	11	7.4	7.4
1.0–5.0	6	4.0	4.0
5.0–10.0	1	0.67	0.67
10.0–50.0	2	1.33	1.33
50.0–100.0	1	0.67	0.67
over 100.0	2	1.33	1.33
	149	100.00	15.4

Data presented by G. R. McCall in Session V

II. Washington, D.C., NCRH survey of 24 brands of color television receivers[11]

X-Radiation Exposure Rate, mR/h	Number of Receivers in Range
<0.040	856
0.040–0.074	52
0.075–0.124	38
0.125–0.249	68
0.250–0.499	44
0.500–0.999	26
1.000–1.999	23
2.000–3.749	5
3.750–7.499	5
7.500–12.500	5
>12.500	2
	1124

III. Location of maximum X-radiation exposure rates in NCRH Washington, D.C., survey[11]

X-Radiation Exposure Rates, mR/h	Number of Sets by Location of the Highest Exposure Rate Measurement*						
	Bottom	Left	Top	Front	Right	Back	Total
0.040–0.074	8	7	12	14	0	11	52
0.075–0.124	6	4	9	11	0	8	38
0.125–0.249	2	23	14	9	0	20	68
0.250–0.499	2	14	4	8	1	15	44
0.500–0.999	6	7	2	3	1	7	26
1.000–1.999	3	6	0	5	0	9	23
2.000–3.749	0	2	0	1	0	2	5
3.750–7.499	0	2	0	2	0	1	5
7.500–12.500	1	2	0	1	0	1	5
>12.500	1	1	0	0	0	0	2
	29	68	41	54	2	74	268

*A number of sets had the same exposure rate on more than one side. The priority for placement in the table is the following: front, left, top, back, bottom, and right. "Left" is the set surface on the viewer's left.

IV. EIA audit summary of television receiver data submitted by 23 television manufacturers

Picture Tube Size, inches	Number of Sets				
	Back-ground, mR/h	Below 0.3 mr/h	0.3 to 0.5 mR/h	Over 0.5 mR/h	Total
14	282	27	—	—	309
18	1 668	742	6	—	2 416
20	1 491	850	—	—	2 341
21*	103	217	—	—	320
22	218	173	2	—	393
23	7 934	5 499	9	4	13 446
	11 696	7 508	17	4	19 225

*Round

Data presented by H. H. Harris and H. O. Wood in Session V

sions could be corrected by replacing the tube and/or properly adjusting the high voltage.

As a result of this publicity, many owners became concerned and requested that their sets also be examined. A second survey was conducted from December 1, 1967, to February 19, 1968, that included 149 color sets of 20 different makes. This time, only 15.4 percent exceeded the standard, 4 percent by a factor of 10 (see Table I); a paper describing the public health and technical aspects of these surveys was presented in Session V of the present conference.

Almost concurrent with the Florida studies, a larger-scale survey of X radiation from color receivers in homes was started on December 16, 1967, by the Technical Services Branch of the National Center for Radiological Health. Results published in a report[11] dated March 12, 1968, indicate that of 1124 sets from 26 different companies tested in the Washington, D.C., area, 856 emitted a lower level than the survey instrument could detect (sensitivity threshold, 0.04 mR/h), and 1058 measured less than the 0.5-mR/h NCRP level. Of the remaining 66 receivers, only 12 exceeded the limit at the front of the set, i.e., toward the viewer. Supplementary use of radiographic film techniques did detect one exposure rate as high as 369 mR/h from the bottom. All were corrected by a high-voltage adjustment or component replacement.

Some results concerning distribution and location of these exposure rates are given in Tables II and III. (A paper by Nelson and Smith in Session V summarized the field survey techniques used by the NCRH.)

Among the conclusions arrived at in the NCRH study, the following are significant:

1. The primary sources of X-ray emissions are the high-voltage shunt regulator tube,* the high-voltage rectifier tube, and the picture tube.

2. The operating high voltage for television receivers demonstrably affects production and emission of X radiation from components.

3. It is possible to reduce X-radiation emissions through service adjustments, including replacement of shunt regulator or high-voltage rectifier tubes, and reduction of the operating high voltage to normal values.

4. The survey technique did not provide data to support a valid association of observed X-radiation conditions with individual brand name or manufacturer on a nationwide basis.†

5. Survey results demonstrate that the industry has produced color television sets that can be operated well within the NCRP recommendation.

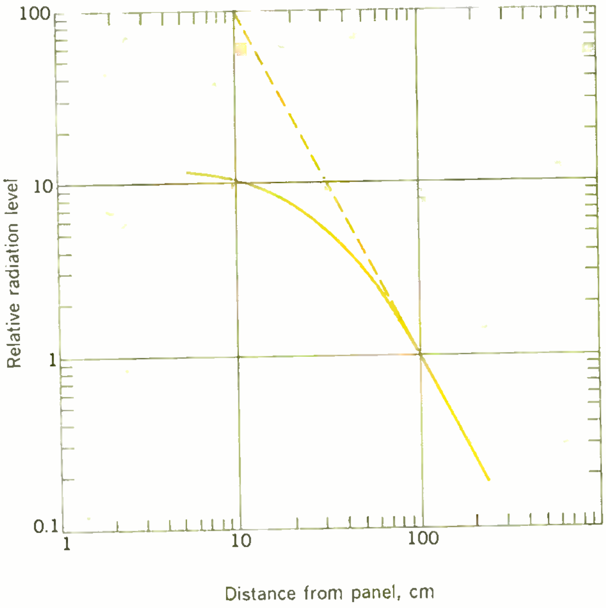


FIGURE 1. Effect of distance from panel on radiation level. Since measurements were made with a large raster and high voltage, there is a maximum deviation from the inverse-square law; hence, this curve represents the worst condition expected.[2]

Between July 1967 and March 1968, the EIA requested a comprehensive audit of television receiver radiation from 23 major manufacturers. In this survey, presented by Harris and Wood in Session V, data were obtained from 19 225 receivers, and only *four* were found to emit radiation above the NCRP standard. This is certainly an admirable record, as can be seen from the results in Table IV. All four were corrected by adjustment of the high voltage, replacement of faulty components, or clearing of an intermittent circuit.

Criteria

As previously cited, two papers of Session II described the NCRP rulings that have been the criteria for X-ray levels from television systems.

In reviewing the "Evolution of the NCRP 1959 Recommendation," Carl B. Braestrup of NCRP declared that the principal objective of the 1946 ASA Code Z54.1, setting a surface limit of 12.5 mR/h on a device, was to remove the likelihood of particular *occupational* radiation hazards. The International Commission on Radiological Protection (ICRP) had already established a rate of 0.2 R/day in 1934, and the NCRP a rate of 0.1 R/day in 1936. "No consideration was given at that time to possible *genetic* injuries affecting the future offspring of irradiated persons" (emphasis added), reported Mr. Braestrup.

In 1949–1950, the NCRP and ICRP both changed the maximum permissible dose (MPD) to 0.3 R/day; and, in 1957, separated the gonad dose requirements into 0.1 R

* Stewart *et al.* have described the construction of these tubes, as well as their X-ray patterns and intensities.[12]

†Although NCRH did not publish brand names in their report, these names have since been released and published in the press.

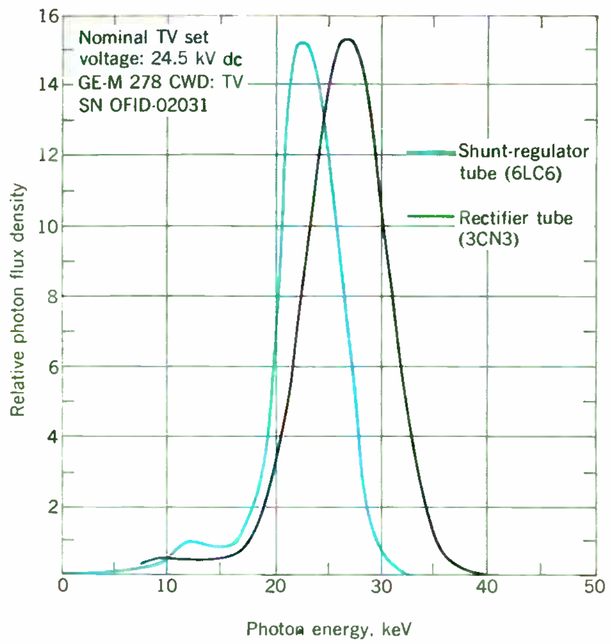


FIGURE 2. X-ray spectra calculated for shunt regulator and high-voltage rectifier tubes (Youmans *et al.*).

per 40-hour week for occupational exposure, and 0.5 R per year for normal exposure. Following suit, the Underwriter Laboratories set a similar limit in 1958.

Although somatic injuries were unlikely at these levels, genetic effects remained a cause for concern. After an extensive study, the NCRP arrived at the conclusion that "the increase in per capita gonad dose from TV receivers should not exceed about 5 percent of that due to the average natural background radiation." Since this background is approximately 100 to 200 mR/year (radiation inside stone houses is twice as high as in wooden ones), the limit was extremely conservative.

Braestrup and Mooney had already determined the relationship between the frontward broad-beam radiation emitted from a television panel and distance[2] in 1959 (shown in Fig. 1), and found that, because the radiation was not a point source, the inverse-square law did not apply for a distance of 100 cm from the set. Assuming the population average viewing time for the year to be 1000 hours at a distance of 200 cm from the screen, and the radiation level at 5 cm to be 0.5 mR/h, they calculated the maximum dose from the television receiver to be only 3.6 percent of the dose from background radiation. They found that the emitted radiation was essentially monochromatic (because of the high filtration effect of the glass wall at the front of the picture tube); also, the radiation emission was reported to be dependent on the operating voltage only.*

In 1959, both the NCRP and ICRP approved the present radiation limits (0.5 mR/h at 5 cm) for television viewers "under normal operating conditions."

Currently, the NCRP is re-examining the 1959 statement because of questions regarding the meaning of such terms as "readily accessible point" and "normal operating conditions," and because of the unique problems concerning narrow nonuniform beams emitted from other areas of the set. An interim statement has recently reaffirmed the "basic intent" of the original decision, however.[1]

Dr. Harold O. Wyckoff of NCRP, in his "Status of the Review of the 1959 NCRP Recommendation," discussed his interpretation of the 1968 NCRP statement.

Recognizing that the introduction of additional components to stabilize the higher-voltage potentials required of color receivers may have created *point* sources of radiation, the Council compromised the position and radiation parameters and selected 10 cm^2 as the area over which to average the exposure, Dr. Wyckoff claimed.

As for the 0.5-mR/h exposure limit, Dr. Wyckoff felt that "the NCRP saw no reason to modify the numerical values given in its 1959 recommendation" in that, although the higher operating voltages create a larger absorbed radiation dose, this increase is not significant to the viewer who is two or more meters from the set. Moreover, because the point-source radiation follows an inverse-square reduction, Dr. Wyckoff maintained that the radiation increase to "nonviewers" was "more than compensated for."

In closing, Dr. Wyckoff suggested that repairmen be warned of the dangers concerning X-ray exposure, "just as they have been alerted to the high-voltage hazard."

As a supplement to the Wyckoff report, D. L. Snow and L. R. Setter of the Standards and Intelligence Branch at NCRH offered "Measurement Considerations in the Development of Public Health Standards Applied to Television." Mr. Snow suggested that the 5-cm distance of the 1959 NCRP ruling may have been determined by the distance from the set being tested to the midpoint of the ion-collecting chamber of the detection device (used by Braestrup and Mooney[2]) when placed directly against the picture tube. Mr. Snow proceeded to outline the six measurement considerations affecting development of public health standards.

He arrived at the following conclusions:

1. X-radiation standards should be based on health-related criteria, and should emphasize the importance of a "virtual absence" of X-ray emission from any color receiver surface.

2. Standard methods for measuring X radiation from television receivers should be developed consistent with the intent of the health criteria.

3. Efforts are encouraged to introduce and develop "performance criteria" (precluding the need to specify only one detection instrument) for these standard methods.

4. Such development of health protection standards for television will "encourage continued technological improvement in instrumentation."

X-radiation characteristics of color television receivers

Session III was divided into two parts.

Spectral characteristics and spatial distribution of X radiation from sources in color receivers. H. D. Youmans, Jr., G. E. Anderson, and Wah Lee of the Radiation Physics Laboratory and Radiation Bio-effects Program of NCRH reported on the "Spectra and Percentage Depth Dose of X radiation Emitted by a Color Television Receiver," supplying data on emissions from

* Actually, measurements at voltages up to 25 kV showed an exponential drop in transmission percentages with millimeter increases in flat-glass panel thicknesses.

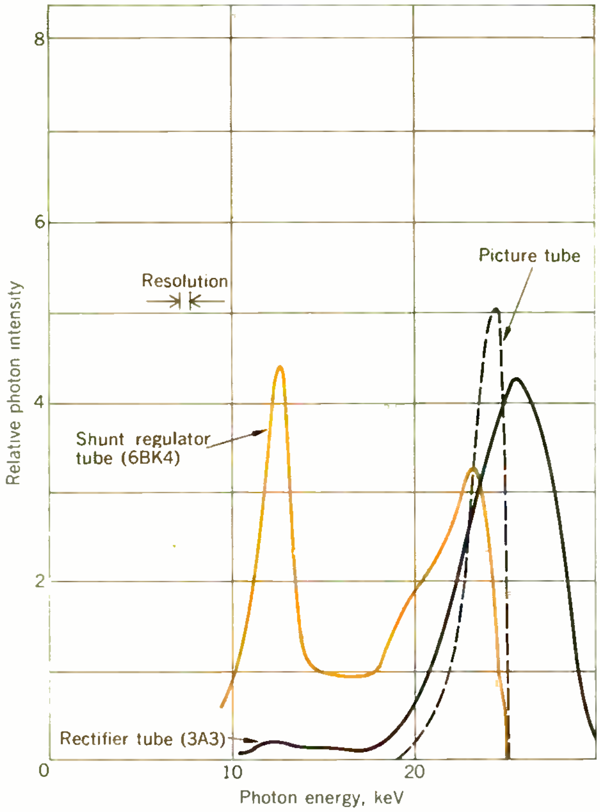
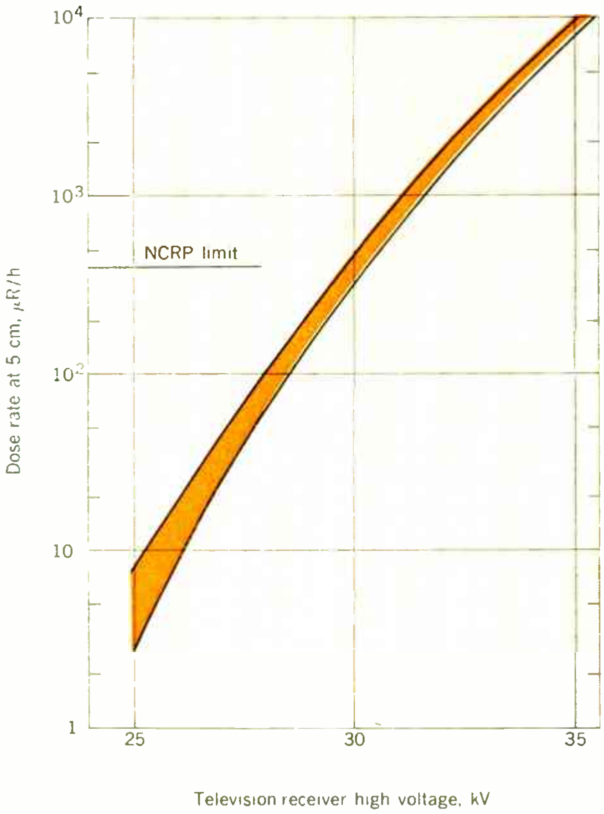


FIGURE 3. Spectral distribution of emission at 25 kV from the three primary sources of X radiation as obtained with a high-resolution Si(Li) detector (Wang *et al.*).

FIGURE 4. Dependence of radiation dose rate upon operating voltage (25-inch color tube, 9019 glass and lamination, full raster, 1-mA anode current). Data were taken with a special high-voltage power supply, since a typical color receiver is not capable of delivering the voltage and current combination needed (Wang *et al.*).



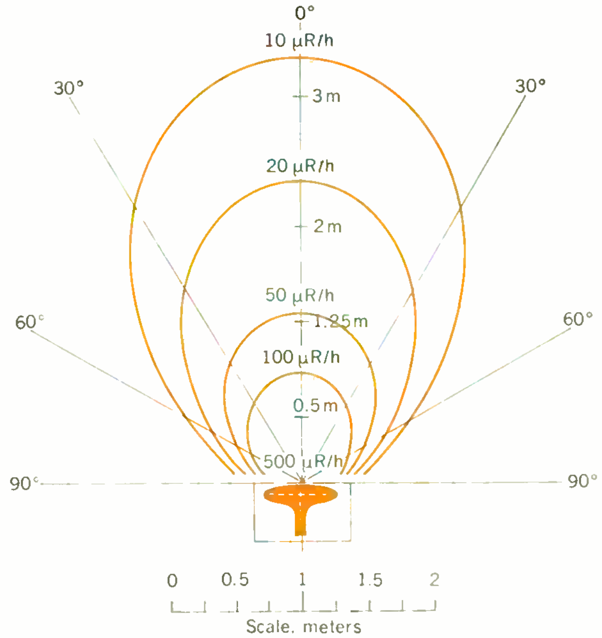


FIGURE 5. Spatial distribution of emission from a typical 25-inch color receiver operated at the NCRP limit (average background = 15 μR/h at sea level; full raster) (Wang *et al.*).

shunt regulator and high-voltage rectifier tubes.

The calculated X-ray spectra for these tubes (Fig. 2) clearly show the narrow range of photon energies associated with these narrow-beam emissions. Regarding the dose rates of human-organ penetration by X rays, Mr. Youmans stated that "depth dose is not only a function of the energy spectrum, but of field size, field shape, and irradiation distance as well."

In the second paper, "Spectral and Spatial Distribution of X-Rays from Color Television Receivers" by S. P. Wang of the Rauland Corporation (a subsidiary of the Zenith Radio Corporation) and S. Savic and H. Hersh of Zenith, Mr. Wang described the results of their study based on the use of high-resolution Si(Li) and high-sensitivity NaI(Tl) detectors.

In reporting the sources of X radiation, Mr. Wang mentioned that a "broad and continuous spectral distribution" of X radiation is created whenever high-energy electrons strike the anode or "any surface at the anode potential." Since more than 80 percent of the electrons in the scanning beam are intercepted by the shadow mask (employed within the picture tubes of most color receivers), only the small remaining percentage of electrons are allowed to pass and illuminate the phosphor screen. Therefore, "the predominant amount of X radiation originates at the shadow mask itself," accounting for more than half of the frontward radiation. Mr. Wang also noted that green phosphor emitted a higher X radiation when bombarded with electrons than blue phosphor, which, in turn, "is higher than that from the vanadate type of red phosphor."* He discounted the funnel part of the picture tube as a major source because of the high lead content of the glass.

* See previous *Van Nostrand* definition relating X-ray levels with atomic weights.

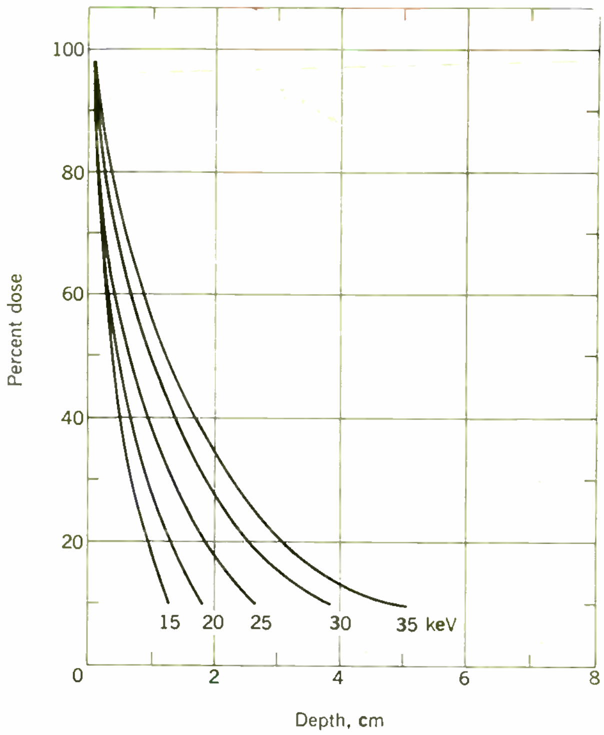


FIGURE 6. X-radiation depth-dose percentages along the central axis. Filter = 0.5 mm Al, focus-skin distance = 27.5 cm, field = 100 cm² (Moseley).

Mr. Wang pointed out that X radiation in a shunt regulator tube is generated at the anode; and in a rectifier tube, at the cathode. The X-ray emission of the rectifier occurs during the reverse (or trace or nonconducting) phase of the sweep cycle, as has been ascertained by Ciuciura[3] and Rechen *et al.*[10] The picture-tube radiation was also found to exhibit a strong correlation with the sweep cycle, whereas shunt regulator tube emission exhibited "very little" correlation. A spectral distribution for all three tubes is given in Fig. 3.

The dependence of radiation intensity upon operating voltage (already described) is illustrated in Fig. 4. Mr. Wang contended that this effect "is primarily due to the escape of freshly generated higher energy photons, which encounter much less absorption as they pass through the envelope of the tube."

The spatial distribution of X rays from a typical 25-inch (63.5-cm) picture tube is displayed in Fig. 5. Mr. Wang's experiments with smaller tubes and 25-inch tubes with smaller rasters indicate that the fading of dose rate with respect to distance is much more rapid. Although spatial patterns for rectifier and regular tubes "differ markedly from tube to tube," in general, the observed dose rate decays as the inverse square of the distance—much faster than for the picture tube—he related.

Citing an example of abnormal operating conditions, Mr. Wang found that line voltage greatly influences the general level of radiation—"a 5-V ac increase in the line voltage [115-V ac] is capable of raising the level by a factor of *two*" (emphasis added).

Relationship between measurements and biological aspects. Following a luncheon recess, Session III continued.

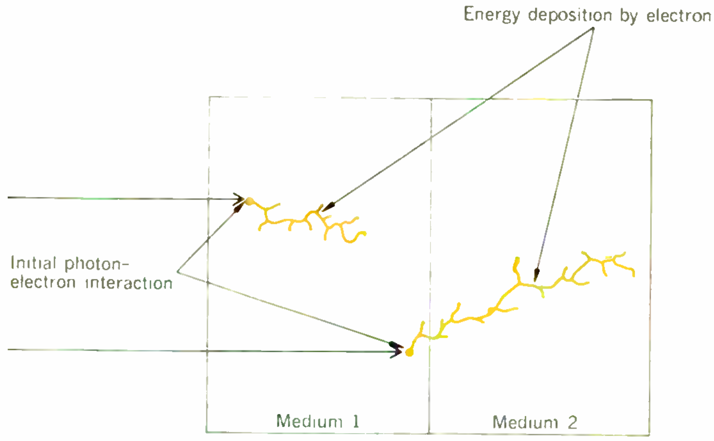


FIGURE 7. The two stages of X-ray energy deposition in matter (Bates).

After a discussion of radiation effects upon organs of major concern (skin, eyes, gonads, bone marrow, thyroid, and central nervous system), as well as the life-shortening and growth-development aspects of radiation, Dr. W. A. Mills (who contributed the paper, "Biological Considerations in Measuring and Evaluating X-Ray Exposures from Color Television Receivers," together with A. H. Wolff and M. L. Shore of NCRH) maintained that, although acute (immediate) effects are highly improbable, late effects from chronic exposure are possibly those of concern; and that color television exposure may contribute significantly to man's total radiation exposure if it exceeds the NCRP recommendation.

Dr. Mills emphasized that instruments able to detect and provide detailed information on narrow high-intensity beams should be developed.

Asserting that the physical properties of radiations created at less than 100 kV are "well known and understood," Dr. R. D. Moseley, chairman of the Department of Radiology at the University of Chicago, proceeded to evaluate the potential radiation injuries that may be derived from low-level low-voltage X rays in his paper, "Biological Considerations of Radiation from Color Television Receivers."

The presentation of isodose curves of various filtration levels, with half-value layers of 0.01–0.1-mm aluminum (6–30 kV), served "to indicate the attenuation of radiation of this quality in tissue." Dr. Moseley used a beryllium window X-ray tube with an inherent filtration of 1 mm of beryllium equivalent to obtain his results. Figure 6 gives a measure of the depth doses attained by Dr. Moseley at up to 35 keV.

Summarizing, Dr. Moseley noted that only a negligible dose of radiation, if any at all, reaches the depth of the most critical organs.

A comparison of these two papers demonstrates how a controversy similar to the present one may arise, and how both the general public and newspaper reporters can easily be confused.

Mills *et al.* presented arguments that tend to maximize the health hazards of color television X radiation, whereas Moseley, using much the same biological information, concluded quite the opposite. For example, Mills included a section entitled "Estimated Dose Calculations"

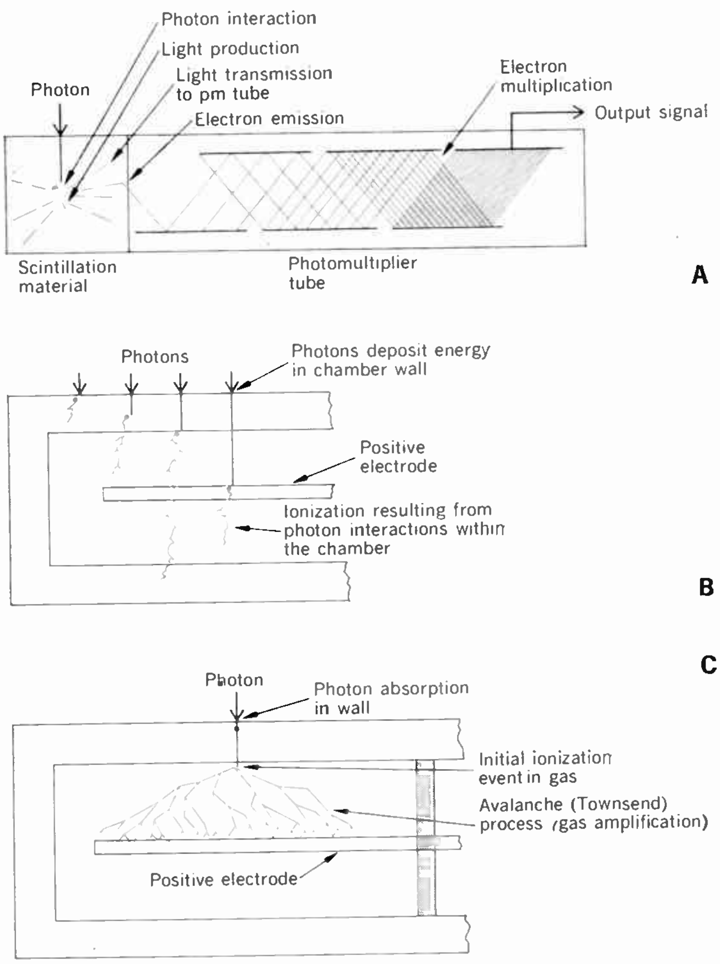


FIGURE 8. Cross-sectional view of three types of X-radiation detectors (Bates). A—Scintillation counter. B—Cavity ionization chamber. C—Geiger-Mueller tube.

in which, for some unexplained reason, he assumes double the NCRP recommended exposure rate at 5 cm. He then uses an assumed figure of 3 percent as a correction factor at 200 cm, instead of the 2 percent measured by Braestrup at that distance. As a result, he is able to say "nevertheless . . . the radiation dose is approximately 10 percent of the FRC recommended limits"—implying an obvious criticism. Had he used the NCRP limit, which is the industry standard, the dose would only have been only 3 percent of the FRC standard, which is 5 R for 30 years.

The Moseley paper is largely devoted to the high "soft" X-ray absorption characteristics of the body, which he believes eliminates the risk of any damage to the blood-forming organs or female gonads, leaving only the eye and the testicles worth considering. As part of his summary, he stated: "The potential for biological damage from these sources [rectifier or regulator tubes] is essentially nonexistent." This conclusion gives quite a different impression from that of Mills *et al.*, and yet there is probably no disagreement at all on the facts.

Measurement systems and calibrations

Comprised of five parts, Session IV was the longest and most actively debated session of the conference.

Characteristics of detectors. The single paper of the first part served to introduce the rest of the session by presenting pertinent aspects of radiological physics.

Dr. Lloyd M. Bates of Johns Hopkins University presented the basic concepts and definitions of X radiation. A *beam of X rays* is a flow of photons, each *photon* is characterized entirely by its energy; a *beam of radiation* is characterized by the distribution of photon energies in the beam and the energy flux density of the beam; *energy flux density* is the sum of the energies of all photons passing through a unit area in unit time; *quantity of radiation* is the time integral of the energy flux density. Dr. Bates described the basic mechanisms, relative sensitivity, and energy dependence of three types of radiation detectors: cavity ionization chambers, Geiger-Mueller (GM) counters, and scintillation counters.

In outlining the absorption process of X radiation, Dr. Bates explained that, in the energy ranges being considered, "low-energy photons are more readily absorbed than those of higher energy." X-ray energy deposition takes place in two distinct steps: first, transfer of all or a part of photon energy to an electron; second, transfer of electron energy to atoms in the medium through which it is moving (see Fig. 7), perhaps resulting in an ionization of the atoms.

Dr. Bates described the roentgen as the unit that, for historical and practical reasons, is currently used as the quantity of X radiation at a point in space—a "unit of exposure," not necessarily the unit of absorption at that point.

Concluding that scintillation counters are the most sensitive (response per unit of incident radiation) detectors, Dr. Bates placed GM counters next and ionization chambers last. He also revealed that energy independence (sensitivity variation with photon energy change) is more difficult to build into GM counters and is easier to achieve in ionization chambers, with scintillation counters in between.

One can easily see why the sensitivities of these detectors fall in this order. The photon energy transfer within the scintillation material is usually entirely deposited in the crystal [Fig. 8(A)], whereas, in the ionization chamber [Fig. 8(B)] or GM tube [Fig. 8(C)], a portion of the energy is deposited in the walls. In turn, the gas amplification caused by the avalanche effect of the GM tube can result in the detection of a single ionization event, which might have gone undetected in an ionization chamber (commercial applications have found the former to be as much as 100 times more sensitive).

Ion chambers. The first two papers of this part described the "Services and Facilities for the Calibration of Soft X-Ray Detection Instruments at the National Bureau of Standards" (Thomas P. Loftus, Center for Radiation Research, NBS), and the "Low-Energy, Low-Exposure Rate X-Ray Transfer Ionization Chamber" of NBS (J. Miller, Victoreen Instrument Company; T. Loftus, NBS; H. D. Barnhart, General Electric Company).

The third paper, "Basic Instrumentation and Calibration for TV X-Ray Measurements" (C. B. Braestrup, NCRP), traced the development of a flat, cylindrical "condenser" ionization chamber that was designed after a reported "X-ray burn" from a television receiver in 1949 (later ascribed to an allergy).

Paper four, "Calibration Techniques for Determining Color Television X-Ray Emission" (J. G. Bellian and

Jack Miller, Victoreen), described the basic calibration procedures developed by Victoreen to calibrate survey meters; and the fifth paper, "Factors Affecting the Design of the EPRL Field Survey Meter" (R. H. Schneider and H. J. L. Rechen, NCRH) was the first of four at the conference that specifically dealt with particular phases of the recent NCRH survey of color television receivers in Washington, D.C. Factors considered in designing the EPRL meter were compliance with the NCRP recommendation, and distribution of exposure rates for "quality control or technical study" reasons.

Geiger-Mueller tubes. The two papers of this part of Session IV gave detailed characteristics about the EPRL meter, starting off the second day of the conference.

In "Instrument for Measurement of X-Ray Emission from Television Sets" (Richard K. Stoms and Edward Kuerze, NCRH), Mr. Stoms outlined the specifications, operating instructions, field tests, and maintenance procedures required for the instrument; whereas, in "Calibration and Energy Dependence of the EPRL X-Ray Survey Meter" (H. J. L. Rechen, R. H. Schneider, and R. K. Stoms, NCRH), Mr. Rechen defined the principles of calibration, energy dependence measurements, and linearity measurements.

Film. In determining the "Low-Energy Calibration of Film Used in Measuring X Rays from Color Television Receivers" (Harold Stewart, Norman Modine, and James Rolofson, NCRH), Dr. Stewart described the calibration of five types of Kodak film by the X-Ray Exposure Control Laboratory for a 1967 test of color television X radiation. His conclusions found film to be "the best detector for permanently recording and measuring in detail the area distribution of X-ray exposures, especially for small X-ray beams such as found from the components investigated." He also found ion chamber survey meters "the best for accurate exposure measurements of broad beams that uniformly irradiate the entire volume of the ion chamber ."

Others. The following papers rounded out the session on measurement systems and calibrations:

"Energy Dependence and Linearity of Response," H. J. L. Rechen, NCRH, and C. H. Williams, Eberline Instrument Corporation.

"Comparison of X-Radiation Rates from Television Receivers Using Commercially Available Instruments of Different Types," S. D. Savic, H. N. Hersh, J. A. Rossi, and R. J. Meltzer, Zenith Radio Corporation.

"Measurement and Calibration of Soft X-Radiation with Pulse-Height Spectrometers," S. P. Wang and R. R. Hayes, The Rauland Corporation.

"The Measurement of X Radiation from Television Sets Using Scintillation Detectors," R. H. Marsh, W. R. Pierson, E. Eichen, and M. A. Short, Ford Motor Company.

"Advantages of a Scintillation Detector for the Complete X-Ray Survey of a Television Set," Wayne B. Hadley, Zenith Radio Corporation. (Time did not permit the presentation of this paper at the conference.)

"Capabilities and Methods to Measure X-Ray Radiation Originating in Television Receivers," W. V. Baumgartner, United States Testing Company, Inc.

Quality control and field evaluation

The first part of Session V started immediately after the luncheon recess.

Present and future industrial procedures for quality control. In presenting the "Underwriters' Laboratories Role in Evaluation and Control of X-Radiation from Color TV Receivers" (A. W. Smoot and L. H. Horn, UL, Inc.), Mr. Horn recognized the previously defined importance of instrument characteristics such as chamber or window size, window material and thickness, energy dependence, and accuracy.

Since 1939, UL, Inc., has inspected the potential hazards of fire, electric shock, implosion, and ionizing radiation from radio and television receivers that have been voluntarily submitted to them. Presently, the number of television receiver models that have met the UL safety requirements are estimated at 7000.

In addition to a preproduction inspection of a manufacturer's appliance under heating, dielectric strength, shock current, high-voltage abnormal, heater short circuit, enclosure heat stability and mechanical strength, picture-tube implosion, X-ray emission, and related safety tests, a follow-up service establishes the fidelity of a production model to the prototype.

Mr. Horn stated that UL inaugurated a monthly inspection schedule of each color television receiver factory (U.S.: 24, other: 9) producing listed sets in September 1967. The Electronic Industries Association has indicated that, since 1947, the United States has produced approximately 120 million television receivers. In the period of January 1964 to May 1967, 11.7 million *color* receivers were produced. Mr. Horn estimated that 95 percent of these have been designed to comply with UL requirements—the "great majority of these receivers" carrying the UL stamp.

The second paper presented a composite view of current "Television Industry Practices and Procedures for Quality Control" (H. H. Harris and H. O. Wood, EIA). After analyzing, from the responses of 23 participating manufacturers, the in-process controls and precautions, quality control and audit procedures, instrumentation, standards, test methods, and control action of the industry, Mr. Harris presented the results compiled in Table IV (previously described).

In an attempt to obtain more brilliance from a failing CRT, a repairman may inadvertently increase the X-radiation hazard by increasing the operating voltage. Recognizing the need to abrogate such practices and to educate servicemen regarding possible dangers, the EIA developed and distributed a "Television Service Bulletin" outlining servicing guidelines in August 1967. This bulletin, in turn, served as a model for the manufacturers in preparing additional literature alerting field personnel to X-radiation hazards. In describing these precautions, Mr. Harris estimated that about two million pieces covering all aspects of the X-radiation problem were mailed to field personnel.

In addition, he stated that the industry attaches two, and sometimes three, "caution" or "warning" labels to every receiver. Often, an insert containing customer instructions regarding X radiation is also attached. Indeed, the industry has gone so far as to include radiation safety as part of the instruction program for field service technicians.

Field survey methods. The first two papers of this part of Session V have already been referred to. "Summary of NCRH Home Television Receiver Survey Techniques" (D. J. Nelson and D. R. Smith, NCRH) was the last paper to describe some phase of the Washington, D.C. survey. "Public Health Aspects of Surveys to Evaluate X-Ray Emissions from Color Television Receivers" (G. R. McCall, Pinellas County Health Department) reported on the initial pilot survey by NCRH and Pinellas County of color receivers in Florida. Results of both of these surveys are given in Tables I through III.

In reporting the "Results of Radiation Surveys of Service Shops in Several Metropolitan Areas" (J. Post, M.D., S. Savic, and G. Walter, Zenith Radio Corporation), Mr. Walter concluded that pursuing a course similar to Zenith's "should obviate any concern about radiation exposure in field service operations."

The final technical paper of the conference, "Techniques for Home Surveys of TV Receivers" (H. N. Hersh, Zenith), offered two approaches for developing *standardized* techniques for future surveys testing compliance with some X-radiation standard: a video-averaging method featuring an on-channel condition with the color picture adjusted by the viewer, and a white-raster method featuring an off-channel condition with the X-radiation level adjusted to maximum. Both methods involve measuring the average dose rate that is emitted from a color receiver, and enable future surveys to be "more reproducible" by standardizing the technique.

Conclusions

The conference was a productive one and fulfilled its intended purpose, placing on record the results of a very considerable effort by industry and government to define radiation characteristics of television receivers and establish measurement procedures and instrumentation. As a result of the meeting, it is hoped that improved, standard methods of measurement will be developed.

The record indicates that a properly operating television receiver emits an extremely low level of ionizing radiation—certainly too low to cause somatic injury. It is significant that no verified instance of radiation injury from television viewing has been reported to date.

However, there remains the question of possible long-range effects. In the last decade, it has been demonstrated that biological repair takes place for genetic, as well as for somatic, effects.[13] In the words of Dr. V. P. Bond, a leading authority on radiation effects upon humans, "it can be stated definitely that the probability of genetic effects at the low [television] doses and dose rates is so low that they could not be demonstrated in subsequent generations even if a very large population of human beings were now exposed." Nevertheless, even though the recommended radiation limit reduces television exposure to a small fraction of the dose from background and medical X rays (most sets radiate much less than this limit), steps should be taken to avoid the generation of extremely high levels of radiation.

At present, both industry and government are responding to the controversy in their own ways: industry, by instituting programs of improvement, control, and education; government, by stimulating further research and by initiating regulatory legislation.

Current legislation

On March 20, 1968, the House of Representatives passed H.R. 10790, "An Act to amend the Public Health Service Act to provide for the protection of the public health from radiation emissions from electronic products," and sent it to the Senate. A subcommittee of the Senate Commerce Committee, with Sen. E. L. Bartlett of Alaska as subcommittee chairman, was still conducting hearings in May.

One difficulty is that at least three bills are currently pending before the Senate—H.R. 10790, a similar bill introduced by Sen. Bartlett and others earlier (S. 2067), and a third bill, introduced by Sen. Lister Hill of Alabama on behalf of the administration (S. 3211), that has been referred to the Labor and Public Welfare Committee. The Library of Congress has made a comparative section-by-section study of the three bills, which appears as an appendix to a recent report.[14]

It is interesting to observe that none of the proposed legislation is limited to X radiation, but is intended to cover "all types of radiation ... if emitted from an electronic product." That interpretation[8] goes on to spell out examples of the nonionizing, particulate, and sonic and ultrasonic sources, including microwave ovens, radar, diathermy machines, linear and Van de Graaff accelerators, sonar, and ultrasonic generators used for medical and industrial-cleaning purposes.

As the chairman of a recent conference on the biological effects of microwaves remarked, the "bill is really an umbrella" to regulate all sorts of radiation devices, including broadcast and television transmitters, industrial applications of microwave heating (as in the food industry), and lasers.[14]

The reverberations of General Electric's errant voltage-regulator tubes may be a long time in dying out!

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13. "Dr. Bond on X rays," *Television Digest*, vol. 8, Feb. 26, 1968.

14. "Biological effects of microwaves: future research directions," special panel discussion at 1968 Symposium on Microwave Power, Boston, Mass., Mar. 22, 1968.

Scanning the issues

Special Note on Specials. It may not be a complete coincidence or connivance that this month the Scanning Department is looking at material exclusively from six special issues of IEEE TRANSACTIONS, which have come in almost simultaneously. It seems more and more that special issues are becoming a popular and effective way of coping with the flood of publications in all specialties, and it seems likely that we shall see more of such issues as time goes by.

Speech Communication Special. Readers of IEEE SPECTRUM may have noted in the March issue this year a report on a panel discussion on future directions of speech research that was held at the 1967 Conference on Speech Communication and Processing in Cambridge, Mass. Now a special issue of the IEEE TRANSACTIONS ON AUDIO AND ELECTROACOUSTICS is publishing many of the technical papers presented at that conference, including the very fine "Keynote Address" given by Prof. Gunnar Fant, one of the most noted investigators in the modern speech field. As Fant notes, speech research is now one of the most intriguing and stimulating fields inasmuch as its interests range from neurophysiology to practical system designs via linguistics, phonetics, physics, psychology, and a dozen other scientific disciplines, of which electrical engineering is but one. Thus, readers with catholic scientific tastes find in modern speech research many exciting crossroads coming together; Fant's review may whet their appetite.

Speech communication research has expanded much during the past 20 years. Fant's view is that the progress has not been quite even. There was a peak of activity and new developments in the years 1948–1953, owing to the impact of the sound spectrograph on research techniques and the now classical work at Haskins Labs, which introduced the language of Visible Speech. At M.I.T., Stevens and Fant started work at the Acoustics Lab, inspired by the application of circuit theory concepts to speech analysis introduced by Huggins. There Fant also began cooperating with Roman Jakobson and Morris Halle on a theory of distinctive features, which has been very influential since. The first parametric speech synthesizer was developed, information theory gave a new framework for discussing speech communication models, and so on. The next seven-year interval, Fant says, from 1953 to 1960, was not equally remarkable, although during that period speech took strong root in Japan. The last seven years, however, Fant sees as the beginning of a new active period, for it is the breakthrough of the digital age, the age of computers in speech research; and it is the period when Noam Chomsky's generative grammar cleaves into the speech research field. Fant foresees a continued upswing in research efforts, a view that seems already well documented by the contents of this special issue. (*IEEE Trans. on Audio and Electroacoustics*, March 1968.)

Solid-State Imaging Special. Ten papers outlining five different approaches to all-solid-state imaging constitute the IEEE TRANSACTIONS ON ELECTRON DEVICES special issue on this important subject. The papers provide a summary of and quick indoctrination in the various competing approaches to the goal of solid-state imaging and they illuminate the current understanding of the light-integration phenomena in solid-state sensors utilizing single-crystalline structures.

Guest editor William F. List notes that the requirements for relatively low-cost, extremely small, highly reliable imaging systems for military, scientific, industrial, and commercial applications provided the impetus for the development of solid-state imaging systems when the evolution of planar semiconductor and active thin-film technologies opened up a new method of approach. Although at this stage of development these systems do not provide performance comparable with conventional electron beam read systems, they have demonstrated that recognizable and usable images can be derived in an all-solid-state form requiring only low supply voltages.

The silicon photomosaic systems reported in this special issue are based on three approaches—simple phototransistor *XY* arrays with external readout, phototransistor arrays with internal MOS switch elements for one-axis addressing, and a complex array that includes not only the actual imaging array but also the entire readout system. An all-thin-film system is described in which both the sensing array and the active element readout system use thin-film components fabricated with compatible processes. Actual image sensing has been achieved with each of these approaches although results presented to date do not seem to indicate any need for panic, editor Glen Wade tells us, concerning at least the short-term future of conventional vidicon tubes. An added paper describes an image converter system in which near-IR radiation obtained from light-emitting semiconductor diodes is converted into visible radiation.

Theoretical analyses are presented for silicon devices together with the results of experimental investigation of the effects of temperature, pulse rate, and sampling pulse level. These studies indicate the performance limitations to be expected with current-state-of-the-art devices and indicate the principal problem areas that must yield to solutions in order to achieve high-quality solid-state imaging. The wide variety of approaches presented in this single thin volume gives the reader a good insight into this rapidly expanding field. (*IEEE Trans. on Electron Devices*, April 1968.)

Electrical Insulation Special. The increasing use of organic dielectrics in the production of supporting insulators for transmission and distribution circuits, as insulation in rotating machinery, for construction of capacitors, for circuit boards, and for many other electrical applications, has resulted in a more penetrating analysis of testing procedures and for the effects of chemical structure and composition on electrical performance at all frequencies and voltages than has been usual for this venerable field. A special issue of the IEEE TRANSACTIONS ON ELECTRICAL INSULATION has this fundamental problem as its underlying theme.

In his editorial, "Cause and Effect," editor Charles L. Petze notes that the necessity for depending upon empiricism constitutes one of the problems encountered today in developing and using better electrical insulation and dielectric materials. We are not yet able, he writes, to identify causes in all cases nor to proceed with assurance from cause to effect. In addition, the chemist, engineer, and physicist are dependent each upon the others for gaining the knowledge and understanding required to ferret out the causes and to employ them constructively in both electric and electromagnetic applications.

For instance, Petze writes, we are all too prone to describe an insulation as "polyethylene" or "polyester" or "epoxy" without pausing to realize that these are only family names that are not adequate to identify the actual dielectric. There are, for example, many different polyethylenes and many more polyethylene compounds, each having its own peculiar combination of properties.

The five papers comprising this special issue illuminate many of the diverse properties and behaviors of dielectric materials, which those who are concerned with more effective applications will wish to study. (*IEEE Trans. on Electrical Insulation*, May 1968.)

Reliability Physics Special. The methods of reliability engineering, writes G. T. Jacobi in his introductory paper to a special issue on this subject, "Reliability Physics," had their origins in mathematical operations research, which was developed during World War II. Reliability engineering was and is still based on a firm statistical foundation. As such, it is generally applied to systems as a whole, concerned with large populations of parts. Questions that it attempts to answer are: "How reliable is this system?" "How reliable are parts sold by a certain manufacturer under this given type number?" "What is the relationship between the (statistical) reliability parameters of a certain part type and the reliability of the system as a whole?"

The use of reliability engineering, Jacobi goes on, in the preceding sense became mandatory after World War II due to the increasingly more complex nature of the weapons systems demanded for the nation's defense. While the onus of design quality was and is on the shoulders of the design engineer, his ordinary methods no longer sufficed for the planning and execution of systems of greater complexity. The term "tyranny of numbers" has been applied to this phase of engineering. Numerical descriptors of reliability were required to replace vague statements such as "best commercial practice." Thus, the statistician was firmly in the saddle as the core scientist in reliability engineering.

Starting thus from the genesis of the field, Jacobi traces its growth through: the Minuteman I weapons system program, which improved the reliability of a selected list of components in some cases by three orders of magnitude; the formation of a number of reliability data centers, which attempted to collect summary data from the various tests in progress throughout the United States and to disseminate these data to a wider class of users; the subsequent development of a technology dealing with failed-parts analysis, in which attention was given to causes of failure and the methods for cure (failed-parts analysis was the first portion of reliability physics to reach the stature of a professional speciality); the development of accelerated testing, which became the second professional specialty to arise under the general heading of reliability physics; the provision of adequate mathematical models for use in conjunction with certain weaknesses of accelerated testing; and, finally, the broadening of the scientific base for understanding individual failure mechanisms, their activating mechanisms, etc., under an Air Force "Physics of Failure" program.

Thus, this highly readable introduction by Jacobi sets the various elements of reliability physics into perspective, and relates them to the prior art and to their proper fields of application. Compared with other recent branches of engineering, Jacobi concludes, reliability physics has enjoyed a relatively orderly growth. At this time numerous investigators are actively advancing the frontiers of knowledge, and bringing within view components, and hence systems, of unimagined reliability.

The central point, Jacobi notes, is that under new methodology parts are subject to radical improvement without the mass testing that was formerly required to assure high reliability under use environment exposure.

Other papers in the issue provide broad descriptions of methods and techniques as well as detailed results from the use of typical techniques. (*IEEE Trans. on Reliability*, March 1968.)

RF Shielding Special. As is the case with many special issues, guest editor Richard B. Schulz writes in the IEEE TRANSACTIONS ON ELECTROMAGNETIC COMPATIBILITY special issue on RF shielding that choosing representative papers for publication and keeping the size of the issue within reasonable bounds was the most difficult task.

The 26 selected papers are grouped for convenience under theory, measurement techniques, experimental results, and design. The theoretical papers cover transmission-related (plane-wave) approaches, cylindrical shielding, and other approaches. The experimental results cover flat sheets and films, boxes, cable shielding, and other structures. Editor Schulz notes that in reading the submitted manuscripts, he felt truly humbled by the sophistication in investigative techniques and the scholarship evident in the theoretical developments. As with other fields, refinement and extension of theory reveal the *why* of shielding considerations so that the *how* can be more readily implemented. (*IEEE Trans. on Electromagnetic Compatibility*, March 1968.)

Semiconductor Lasers Special. A subject of still rather specialized interest, but one which has grown sufficiently in the last five years to merit a topical conference and a special issue of the IEEE JOURNAL OF QUANTUM ELECTRONICS, is that of semiconductor lasers. J. I. Pankove, guest editor of the special issue that contains most of the papers presented at the 1967 IEEE Semiconductor Laser Conference, notes that although he and Professor Aigrain thought in 1956 that the field of injection lasers would soon develop into a multilaboratory effort, it was not until 1962 that the simultaneous successes of several research teams really launched developments in the field.

Pankove briefly reviews the topics included in the conference sessions—they ranged from theoretical considerations, such as how gain may be distributed spatially in the active region, or how it should depend on current, to detailed performance design in terms of geometry, reflectance, thermal properties, and even in terms of parameters of electron-beam pumping. Temperature dependence, new information on the degradation mechanism of injection lasers, modulation of lasers in the tens of gigahertz, new structures, and new modes of lasing operation were included among other subjects taken up at the conference.

Problems still remaining in the field of semiconductor lasers, Pankove writes, include: the spectral gaps still to be filled; the need for new material or new pumping techniques to permit operation in the visible and UV portions of the spectrum where the most sensitive detectors are available; CW operation at room temperature, an old challenge; and the need for a definitive understanding of the nature of degradation that might, Pankove speculates, push the limit of useful power to higher levels. (*IEEE Journal of Quantum Electronics*, April 1968.)

Advance abstracts

The IEEE publications listed and abstracted below will be available shortly. Single copies may be ordered from IEEE, 345 East 47 Street, New York, N.Y. 10017. Prices are listed with the abstracts of each publication; libraries and nonmembers outside the United States and Canada should add \$0.50. (M—Members; L—Libraries; NM—Nonmembers.)

Copies of individual articles are not available from IEEE but may be purchased from the Engineering Societies Library at the foregoing address.

Proceedings of the IEEE

Vol. 56, no. 7, July 1968
M—\$1.00; L—\$1.50; NM—\$2.00

Large-Capacity Semiconductor Memory (*Invited Paper*), *D. A. Hodges*—Integrated-circuit memories using bipolar transistor technology are compared with memories based on various forms of the insulated-gate field-effect transistor (IGFET). A combination of p-channel IGFET memory cells with bipolar transistor access circuits appears to offer a desirable combination of characteristics. Memory organization, chip design, packaging, and interconnection alternatives are considered. Beam-lead sealed-junction technology has significant advantages over other packaging and interconnection technologies in the realization of semiconductor memory. Some of the problems expected in the design of a million-bit computer memory are examined, with attention to power dissipation, interconnections, reliability, maintainability, and cost. Finally, the potential characteristics of a million-bit semiconductor memory based on today's technology are compared with the characteristics of ferrite core, planar film, and cylindrical film magnetic memories. The conclusion drawn from this exploratory study is that semiconductor memory has attractive potential for both small- and large-capacity memory applications.

Dynamic Scattering: A New Electrooptic Effect in Certain Classes of Nematic Liquid Crystals, *G. H. Heilmeier, L. A. Zanoni, L. A. Barton*—A new electrooptic effect in certain classes of nematic liquid crystals is presented. The effect has been termed "dynamic scattering" because scattering centers are produced in the transparent, anisotropic medium due to the disruptive effects of ions in transit. The ions can be produced by field-assisted dissociation of neutral molecules and/or Schottky emission processes. The rise times of 1 to 5 ms, and decay times of less than 30 ms, together with dc operating voltages in the 10- to 100-volt range, make dynamic scattering seem attractive for such applications as alphanumeric indicators, and do not preclude its use in line-at-a-time matrix addressed, real-time displays. Reflective contrast ratios of better than 15 to 1 with efficiencies of 45 percent of the standard white have been demonstrated.

Exact Equation for Calculation of Sheath Proximity Loss of Single-Conductor Cables, *T. Imai*—The sheath proximity loss of single-conductor cables is calculated by Miller's equation. However, this equation involves a correction term, which causes considerable error in the calculated values for large-size, aluminum-sheathed cables. Taking the self-inductance of eddy current into account, the exact equation is derived. Miller's equation is no longer valid, especially for large-size, aluminum-sheathed cables.

A Network Description for Antenna Problems, *A. C. Gately, Jr., D. J. R. Stock, B. R.-S. Cheo*—A complete network description for an antenna is realized via a modal decomposition of the electromagnetic fields surrounding the structure. The representation contains the transmitting, receiving, and radar scattering properties of the antenna. A scattering formulation permits the antenna's power gain, directivity, effective area, and radar cross section to be expressed as a functional on the elements of its scattering matrix. For an array of antennas, the excitations that optimize its power gain and the loading network that maximizes its radar cross section are determined. The philosophic approach of circuit theory is employed for describing physical antennas. A set of canonical antenna elements having simple properties is defined. An actual physical structure is represented as an array of canonical elements. The method is applied to the case of a Yagi–Uda array. The possibility of loading the array with active impedances is investigated.

High-Speed Ultrasonic Digital Delay Line Design: A Restatement of Some Basic Considerations, *E. K. Sittig*—In the past, ultrasonic delay lines in digital storage applications tended to be designed for a maximum storage capacity compatible with losses in the delay medium in order to minimize the cost of access circuitry. This approach yielded capacities upward of 20 000 bits per delay line but necessitated complicated arrangements to fold up the relatively long delay path in an acceptable space. It also required delay materials with a low ultrasonic propagation loss and accurate temperature stabilization, and resulted in comparatively long average access times to a given bit of information in the store. The emergence of inexpensive access and retiming circuits, however, suggests that delay line stores may be made at lower cost by subdividing them into modules of smaller capacity, and regenerating and retiming the bit stream in each module. This approach leads to design considerations different from the previous approaches and causes requirements of mechanical precision and temperature stability to be lowered. The design procedure described predicts that with presently available materials delay lines can be built that store about 1000 bits at bit rates in excess of 100 MHz, with insertion losses at band center of less than 20 dB and spurious signal suppression of at least 20 dB. Such lines have a storage density of more than 10^5 bits/inch^3.

Satellite VHF Transponder Time Synchronization, *J. L. Jespersen, G. Kamas, L. E. Gatterer, P. F. Macdoran*—An experiment is described that was designed to transfer accurate time between two widely separated clocks using a VHF satellite transponder. The satellite used was the NASA Applications Technology Satellite, ATS-1. The experiment used atomic oscillators to maintain accurate time at each station, and the synchronization was accomplished by measuring the round-trip delay times between the stations. The goal of the experiment was to evaluate a VHF system, because of the low-cost ground equipment involved, in contrast to microwave systems.

Proceedings Letters

Because letters are published in PROCEEDINGS as soon as possible after receipt, necessitating a late closing date, we are unable to list here the letters in the July issue. This will appear in the next issue of SPECTRUM. Listed below are the letters from vol. 56, no. 6, June 1968.

Electromagnetics and Plasmas

Radiated and Reactive Powers in a Magneto-Ionic Medium, *T. Phadi, S. R. Seshadri*

Comments on "Vector Scatter Theory Applied to Moon and Venus Radar Return," *A. Erteza, B. K. Park, L. W. Thacker, A. K. Fung*

Circuit and System Theory

Transient Analysis of TEM Transmission Lines, *Y. K. Liu*

Minimal Reactance Realization of *n*-Port Active *RC* Networks, *B. J. Mann, D. B. Pike*

On the Evaluation of e^{AT}, *A. K. Choudhury, D. R. Choudhury, B. Roy, A. K. Mandal*

Time-Domain Analysis of Multiconductor Exponential Lines, *H. Hagiwara, S. Okugawa*

Transfer Impedances and the No-Amplification Property of Resistive Networks, *G. E. Sharpe, D. J. H. Moore*

Adjoint Equation and Solvable Nonuniform Transmission Lines, *S. Yamamoto, K. Sawai, K. Itakura*

Electronic Circuits and Design

Theoretical Effects of Overlap Capacitance Upon MOS Inverter Output, *B. Bazin, R. H. Crawford, L. J. Sevin*

Comments "On the Intrinsic Time Variance of Fast Timing Circuits Using Tunnel Diodes," *D. E. Nelsen, A. Barna*

A New Astable Multivibrator Generating Triangular Waves, *S. Chang*

Comment on "Computer-Aided Design of Varactor Multiplier Circuits," *C. B. Burckhardt, P. E. Green*

An Active Dual-Input *RC* Notch Filter, *U. S. Ganguly, S. Das*

Electronic Devices

Fast-Sweep Capacitance-Voltage Plotter, *E. J. Charlson, D. H. Hu, T. H. Weng*

Pulse Millimeter Power Using the LSA Mode,

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to see both the demonstration of the telegraph, and an exhibit of scientific instruments collected by King George III and presented by Queen Victoria to King's College, designated as the Royal Museum and placed under Wheatstone's direction. Prince Albert and his party were shown the exhibit presented by the Crown and the other instruments in possession of the college, some of which had been designed by Wheatstone. Afterwards, the group went to see Wheatstone operate the telegraph [Ref. 2 of article].

"After presenting his design of a submarine telegraph in 1840, Wheatstone continued to make plans, and obtain components for a demonstration, and by 1844 conducted an experiment in Swansea Bay, which consisted in the transmission of signals by telegraph between a boat and Mumbles Lighthouse [Ref. 3 of article]."

In preparing the condensed story for IEEE SPECTRUM, the above passage was unhappily truncated. It has not been my intention to dwell on the various models of the telegraph, as these have already been discussed extensively.[3-5] (Ref. 2 of article.)

In reply to paragraph 6, I quote from Wheatstone's formal report (p. 90, Ref. 4 of article): "The experiment was tried at the Gallery in Adelaide Street." Later, on page 95, "The sparks from the great magnet constructed by Mr. Saxton, which was at the Gallery in Adelaide Street, were considerably elongated even when the mirror was moving with a comparatively low velocity."

Regarding the last paragraph, once more I disagree with Mr. Garratt, and my position is well established in the literature.[6] "In 1834, Charles Wheatstone, Professor of Experimental Philosophy in King's College, London, by examining in a revolving mirror sparks formed in the extremities of a circuit, found the velocity of electricity in a copper wire to be about one and a half times the velocity of light. . . . The large value of the velocity found by Wheatstone was mainly due to the fact that his wire was not straight, but was coiled in twenty straight windings: and the effect travels in a zig-zag or spiral wire more quickly than a straight one."

This experiment was neither simple nor straightforward, but ingenious and sophisticated. I quote from the obituary in *Nature*.[7] "The President of the Italian Society of Science, of which he [Wheatstone] was made an honorary member in 1867, said, in conferring the honour, that the applications of the principle of the rotating mirror are so important and so various that this discovery must be considered as one of those which have most contributed in these latter times to the progress of experimental physics."

If Wheatstone had been able to anticipate the contributions of his nephew (Oliver Heaviside) to the theory of the telegraph, and had designed the conducting *path* of the propagating electromagnetic impulse as Heaviside might have a half century later, and had used Heaviside's theories to interpret the results, he would have been able to make his apparatus yield the velocity of light within 0.1 percent.

B. R. Gossick
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IEEE communication

In going through the article entitled "IEEE Headquarters—People, Facilities, and Functions" by the General Manager of IEEE, in the December 1967 issue of IEEE SPECTRUM, I felt that Mr. Fink had brought the ordinary member of the Institute much closer to the Institute by giving him an insight into the working of the Institute's Headquarters. Such introductions to the Regional offices and the leading members from all parts of the world would be very useful for the members and create a greater sense of brotherhood among them.

It would be useful if similar articles concerning Regional organizations were also published in IEEE SPECTRUM. In addition to these articles, there should be a program of interchange between Regional representatives. Temporary attachment of a member of one Regional office to Headquarters or to another Regional office would help in generating close cooperation between the Regions and Headquarters. This is especially true in the case of the European, the South American, and the African/Asian Regions.

Finally, I hope that the General Manager of IEEE will be able to put these suggestions into practice, and continue the good work started with his article.

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Pure-science payoff

The "Spectral lines" in the April issue of IEEE SPECTRUM, as well as Hamson's letter in the same issue, deserve further comment. Sooner or later, science and scientists must decide what the relationship is between science and the public whose support makes it possible, and whether the supposed connection between "purity" and "uselessness" is anything but snobbishness.

I agree completely with Hamson that science, along with all other activities supported by the public, should be subject to some sort of cost-effectiveness criteria. Said another way, the benefits to the public must justify the costs.

This leads to the next question. Can these benefits be measured, and are they all a generation away? It appears that a number of alleged conclusions of Project Hindsight have already become embedded in popular mythology, and it may be impossible to uproot them. A careful reading of the Hindsight reports shows that they did not find any such thing as a "40-year lag" between undirected science and technology. Instead, what the reports show is that, for the 30-year period studied, very few applications of undirected science were found from science of any period. That is, Hindsight investigators did not find many applications of old science and few of new science—they did not find applications of science at all.

Further study shows that this is the result to be expected. In fact, the surprising thing is that they found any applications at all. The Hindsight methodology almost inevitably leads from technology to technology, and was not well suited to tracing the path from technology back to science.

The Air Force Office of Scientific Research, which, with the Army Research Office and the Office of Naval Research, supports basic science in universities for the Department of Defense, has made a sizable study of the results accruing from its own research by starting with a research result and tracing it forward to application. One such study, which found IEEE journals playing a major role in the transmission of scientific results to technologists, is reported in Ref. 1. A major study of several results is reported in Ref. 2, and in more detail in Ref. 3. This approach has proved highly successful.

To answer Hamson's question, it *is* possible to demonstrate the payoff from science, and to show that the payoff can be realized in only a few years, perhaps even during a single Administration. What is needed is a greater effort by scientists to demonstrate this to the public, and to the public's elected representatives. Then, perhaps there would not be so much concern with loss of financial support. No elected official is going to reduce the support of some activity that he and his constituents believe is beneficial to them. Once scientists show that science pays off, they won't need to claim that it should be supported for its own sake.

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2. Martino, J. P., "Is basic research relevant to military problem solving?" *Armed Forces Management*, Nov. 1966.
3. Price, W. J., Ashley, W. G., and Martino, J. P., "Relating the accomplishments of AFOSR to the needs of the Air Force," AFOSR report, Clearinghouse for Federal Scientific and Technical Information.

It is doubtful that Mr. Martino read carefully enough. In C. W. Sherwin *et al.*, First Interim Report on Project Hindsight, Office of the Director of Defense Research and Engineering, Washington, D.C., June 30, 1966, the section headed "Conclusions" says in part (p. 13): "There is no question that over a long time scale undirected research has had great value. . . .Without the organized body of physical science extant in 1930. . .only a fraction of the technological events [considered in the report] could have occurred. Thus, in the past, in at least these areas, undirected research has paid off on the 30- to 60-year or more time scale. In our study, we see no evidence that this situation has changed."

Editor

Book reviews

Threshold Logic, P. M. Lewis, II, and C. L. Coates—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y., 1967; 422 pages, illus., $15.* This book, certainly a very welcome addition to the literature of threshold logic, has good coverage of pertinent topics and extensive references. Abundant examples illustrate theoretical development, and many new results are presented by the authors.

The synthesis procedures that the authors developed are presented consistently and in detail. Their presentation is greatly improved, which is gratifying as the authors might be expected by readers to present a complete revision of their past contributions. However, the authors use nearly 40 percent of the text on their synthesis procedures, and consequently many interesting contributions of others are either not discussed in proper detail or are completely ignored. The work therefore resembles a monograph, rather than an introductory book to threshold logic. Their synthesis procedures are interesting but look very complex, at least to the reviewer; and their presentation of procedures seems to be repetitive.

Differing from the authors' point of view (page 27), the reviewer feels that most network synthesis procedures, including the authors', are complementary, since there is no single, efficient method to use in designing an optimum network. For example, the linear programming approach could be employed on each threshold gate to obtain reliability after a network is designed by the authors' procedure.

Objectives of designing networks vary; this is even more apparent with integrated circuits, since the minimization of the number of gates, or levels, does not necessarily yield the "best" network. A different procedure may serve a different objective.

Chapters on other subjects, such as Chapters 7 (duality and related *T*-gate realizations) and 10 (adaptive methods), on the other hand, are very well presented and illuminating. In Chapter 7, interesting theoretical properties of threshold functions are presented; and Chapter 10 is an excellent introduction to adaptive networks.

Chapter 9 (methods for solving simultaneous inequalities) is not well developed. The reviewer wonders why the solution of the primary linear programming problem for the maximum relative gap (section 9.8) is included if the same problem can be solved more efficiently by the dual linear programming problem, as the authors point out in the footnote on page 375. The solution efficiency of the dual linear programming problem, which was initiated by Toda, Takasu, and the reviewer, was improved by Winder by taking the differences of the weights. It was recently improved further by Tsuboi, Baugh, and the reviewer by eliminating inequalities in the dual linear programming problem ("Enumeration of threshold functions of eight variables," Report No. 245, Dept. of Computer Science, University of Illinois, Aug. 1967).

As opposed to the authors' view, the reviewer believes that the solution of the dual linear programming problem of realization of a threshold gate by the simplex method is more efficient, and requires less computation, than the authors' tree procedures. Also, it gives a single-threshold gate realization, if a given function is a threshold function, whereas the authors' procedures require more than one threshold gate for some threshold functions.

Misprints and mistakes are few. Reference to papers appear accurate in most cases, but there are some errors. For example, the paper by Yajima and Ibaraki (included in the authors' references) should be mentioned in relation to the lower bound on the number of threshold functions on page 431. No output transformer is needed for the parametron in Fig. 1.10 on page 14. The synthesis procedure discussed on pages 246–247 is erroneously referred to the reviewer's paper. The synthesis in the reviewer's paper is quite similar, but a network is to be designed under the requirement that input variables are available only at the first level of the network. As the authors pointed out in the footnote on page 256, a network synthesized under this requirement has greater advantage in speed than those of pages 246–256 when information is supplied successively. Therefore, the reviewer's network cannot be compared with those of Minnick or Kautz, since the objective of his network is different.

Statement A of Theorem 9.6 (page 383), about primal and dual linear programming problems, is a serious mistake. There exist cases where the dual variables corresponding to primal equalities are zero. The rest of the section should be rewritten, or an appropriate assumption should be added. In Appendix B the proof of the bound on the number of threshold functions on pages 431 and 432 is wrong, as Winder pointed out. (See Winder's unpublished memo, "Threshold Logic Asymptotes.")

In conclusion, this book is a unique source of information for readers who want to learn the authors' synthesis procedures. However, if the reader wants to learn threshold logic in general, he should read additional pertinent papers, even though this book is still a good starting point. Winder's survey ("The Status of Logic"), presented at the First Annual Princeton Conference on Information Sciences and Systems, March 1967, would be an excellent guide.

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Electronics in the West—The First Fifty Years, Jane Morgan—*The National Press, 850 Hansen Way, Palo Alto, Calif., 1967; 188 pages, illus., $4.95.* This book puts some of the pioneering developments underlying today's ever-expanding communications and electronics industry in focus as to origin and locale. It is a noteworthy historical contribution to the story of electrical engineering progress.

Jane Morgan and her sponsors somehow became aware of the quite unique situation of a rather small central California area in which young experimentalists of vision and ability were able to produce individually many outstanding engineering achievements. Other enterprising men were attracted to this area and, over a span of just a few years, produced further discoveries and established industrial enterprises to exploit them. The names of many of these pioneers are familiar everywhere; and some of the businesses have grown to national and international importance.

Commencing just before the turn of the century, this narrative describes early wireless telegraph transmissions in San Francisco, when Marconi's first primitive experiments in England were only months old. Continuing, it tells of boys