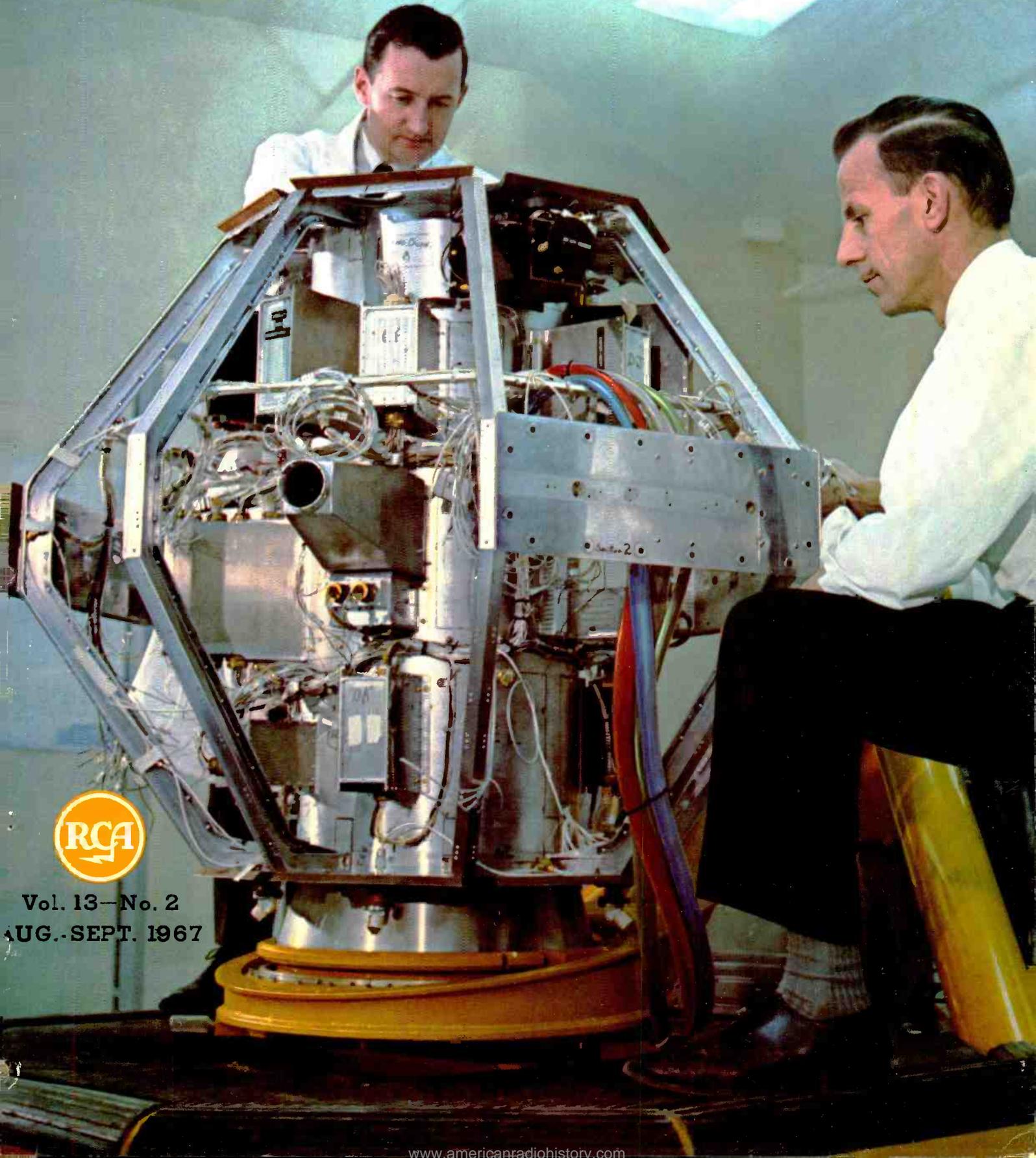


RCA ENGINEER



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OUR COVER

..... the Engineering Model of the ISIS
A spacecraft now undergoing systems testing
in the Aerospace Engineering Laboratory, RCA
Victor Company, Ltd., Montreal, Canada. Carl
Gaul, RCA Victor technician (left) and Dave
Lambert, de Havilland Aircraft of Canada
Designer, are making adjustments. Construc-
tion and test of the flight model has started
and will continue until the Spring of 1968.
The spacecraft will then be shipped to God-
dard Space Flight Center, Washington, D.C.,
for environmental tests by NASA and launch
from the Western Test Range at Vandenburg
AFB, California.

Canadian Satellites and Space Communications

Our guiding principle of developing specialized skills in areas which complement rather than duplicate those of other parts of RCA has led toward an emphasis on telecommunications. Among the many modern trends in electronics, telecommunications provides great opportunity for the growth and future development of technical products in RCA Victor Company, Ltd.

We had already earned a position of leadership by 1964 in this field through the successful completion of several major microwave systems, including one spanning the continent between Montreal and Vancouver. These systems use equipment developed by our Montreal engineers and engineers of the Broadcast and Communications Products Division in Camden. Since then, our engineers have completed development of a new series of solid-state, RF, and modulator-demodulator equipment for use in both overland and satellite telecommunications systems. This experience, plus our expanded knowledge of antennas and related items, led toward emphasis on the satellite earth stations described in this issue.

Thus, space communications via satellites continues to be a major influence in determining our research and engineering development programs. We have worked closely with Astro-Electronics Division in developing and manufacturing the transponder for RELAY I and II satellites, and since then have taken on the overall job of designing and manufacturing the Canadian Isis A scientific satellite, a follow-on from the successful ALOUETTE I and II ionospheric sounding satellites. We served as prime contractor in the supply of Canada's first satellite communications earth station located in Nova Scotia; this facility is now engaged in commercial transatlantic service and will later become a part of NASA's advanced technological satellite program.

To foster a continued growth of our chosen areas of specialization and achieve a competitive position in world markets, we must further develop our skills in dealing with the many problems and opportunities unfolding the world over. We are grateful for the close association between Montreal engineers and their associates in the U.S.A. An interchange of technical information has, through the years, been of immense benefit to us. Our goal is to steadily increase this interchange and enhance further our contribution to the advancement of technology; in so doing, we strive to play an active role in the growth of RCA's total business.



J. D. Houlding, President and Director
RCA Victor Company, Ltd.
Montreal, Canada





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A TECHNICAL JOURNAL PUBLISHED BY **RADIO CORPORATION OF AMERICA**, PRODUCT ENGINEERING 2-8, CAMDEN, N. J.

● To disseminate to RCA engineers technical information of professional value. ● To publish in an appropriate manner important technical developments at RCA, and the role of the engineer. ● To serve as a medium of interchange of technical information between various groups at RCA. ● To create a community of engineering interest within the company by stressing the interrelated nature of all technical contributions. ● To help publicize engineering achievements in a manner that will promote the interests and reputation of RCA in the engineering field. ● To provide a convenient means by which the RCA engineer may review his professional work before associates and engineering management. ● To announce outstanding and unusual achievements of RCA engineers in a manner most likely to enhance their prestige and professional status.

RCA ENGINEER articles are indexed annually in the April-May Issue and in the "Index to RCA Technical Papers."

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Editor's Note: The success of a technically oriented industry such as electronics depends strongly on the role of the engineer—his transition from college to industry, his degree of involvement, and his continued professional development. These are some of the factors discussed by Dr. Brown in a talk ("Staffing An Industry") given in May 1967, before the Congress of Canadian Engineers, Montreal. His complete speech is published here.

The Engineer and the Corporation
TO STAFF AN INDUSTRY
**—A Discussion of the Engineer's
Role in Electronics**

DR. GEORGE H. BROWN
*Executive Vice President
Research and Engineering
Radio Corporation of America
Princeton, New Jersey*

I SHOULD preface my remarks today by stating that I am unable to write a reliable prescription to cure the problems relating to staffing a technically based industry. Rather, I shall confine myself to some observations derived from my over thirty years experience in the electronics industry. While I shall no doubt neglect the problems relating to many of the varied roles of engineers in our society today, I do this not from lack of appreciation of the importance of civil or mining engineering but from an awareness of the shallow knowledge I possess in these areas.

ELECTRONICS: COMPLEX, ALIVE, AND DYNAMIC

Few are the industries that today can continue a famous product unchanged and unimproved, though some patent-medicine makers seem to do so. With the possible exception of the chemical industry, none can surpass the electronics industry for change as a way of life. Electronics pervades all aspects of our modern society. The electronics industry has at least two roles. One is that fulfilled by the manufacture and sale of products which go directly to the private citizen, that is to say, the class of products known as "home instruments," the radio, the television set, or the record player. The other is that

fulfilled by the manufacture of products or devices which furnish the techniques used in other major industries. Examples are the automotive and aircraft industries, the chemical and pharmaceutical industries, the broadcasting and communications companies. There are so many different facets to electronics that no one company, however large, can embrace them all.

An industry so alive and dynamic is made up of a complex of companies varying in size and degrees of specialization. There are some very large companies, a much larger number of intermediate size, and thousands of very small ones filling many ecological niches in the general economy.

START SMALL AND GROW ON MERIT

Before approaching the topic of staffing, we might consider the evolution of a typical company even though we know very well that there is no really typical company. The big companies grew to greatness by starting small, winning public confidence with timely quality products, and expanding with increased demands for the products. Earnings were reinvested in expansion of facilities and work force, including engineers. Some companies grew by acquisition and consolidation of a number of small companies or by mergers of larger entities. But each element had to start small and grow on merit.

As a small company grows, its products depend more and more on engineering concepts and inventions. This develops the need not only for more engineers but also for more kinds of engineers. It also requires more kinds of nontechnical people. A new business built around the knowledge of a small group, who may have migrated from a large company, soon has to have assistance of mechanical and chemical engineers and, eventually, of plant and facilities engineers. There will probably grow a need for the design of special production machinery. As production increases, so will the requirements for factory production engineers, packaging engineers, materials and process engineers increase. As the entrepreneurs use up their initial store of knowledge that gave rise to the initial successes, they will have to undertake new developments and a measure of research.

COMPETITION AND INNOVATION

A well-balanced concern must keep its corporate eyes on competition and costs, while developing a technical organization with a scale of reasonable salaries from that of the new engineering graduate to that of a chief engineer. Some of the original working engineers may now become leaders of a group, with progressions to management of even larger groups. Up to a point, the chief engineering manager or executive can be personally acquainted with every person in his group or even his company. Eventually this becomes impractical if not impossible, at least for the top executives.

By the time a company has progressed that far, something has generally happened to the whole industry to exert external pressures. To have been successful means that a company has gradually adjusted to changes—the impact of market evolution or competitive pressures. A really viable company has also produced its own impact on others through innovations and imaginative concepts adapted to real needs of users. But often the opposite may happen. The original people may run out of their store of knowledge and are unable to keep the pace. If they are too specialized, the need for their product may vanish.

They can sometimes revitalize and reorient their staff by hiring engineers with skills and knowledge more in tune with the times. They may diversify their work so that they can sustain the demise of certain products while prospering with others. If the technical and economic management has been good, the company may increase rapidly in size, big enough to buy smaller ones that round out its needs or to merge with another.

So in most industries, particularly in the electronics industry, there are great numbers of companies at all stages of growth, from the new ambitious beginners to the venerable giants employing thousands of engineers of many disciplines.

TRANSITION FROM COLLEGE TO INDUSTRY

Now let us look at the individual engineer in industry. What is his life? Certainly if he has exhibited the discipline, the endurance and the devotion to complete a sound engineering course in a university, he comes to industry with enthusiasm and ambition. A wise management will not expect too much of him for a year or two as he adjusts to the strange new demands of industrial duties. He will study diligently and have the inspiration of exposure to experienced men. He masters one small area of work and learns how it fits into the work of others. He endures the drudgery of solving sticky problems and enjoys the elation of surmounting them. In time, he becomes recognized in his company, and perhaps outside of it, as an expert in some aspect of technology. Unless he settles down to be a technical provincial who is satisfied with higher and higher degrees of specialization, he will expand his interests and take every opportunity and responsibility to extend his fields of expertness, but taking care not to be too superficial.

CONTINUED GROWTH

With continued growth and advancement, he may become leader of a group or a large project team. As he approaches manager status he must become accustomed to the difference between working with things or with people, and begin to realize the change that comes now with working with men and ideas and money. He must console himself with the realization that he cannot keep up technically with all his men, that it is deadly to try to compete with them, but yet he must maintain his technical growth in order to comprehend what goes on, to appraise alternatives, and to judge fairly his men's competence. He must also represent his men before higher management. Of course, his responsibility has increased many fold at this stage and many hard decisions have to be faced. He is constantly faced with the task of evaluating ideas, results, and people.

PERSONAL PROFESSIONAL DEVELOPMENT

A universal characteristic of any engineering career in modern industry is one's role as a member of a team of workers whose collective effort and skills come together to achieve results unachievable by a galaxy of individual stars. As an industrial employee and particularly as a team member, the industrial engineer never appears to the general public as a professional man. He does not appear before the public in the same way as an architect, a physician, or even a consulting engineer. Yet he *is* a professional man and is so recognized by his associates and in the professional societies. Most companies today have very liberal publication policies which enable engineers to publish much valuable proprietary information which brings



DR. GEORGE H. BROWN studied at the University of Wisconsin, receiving his BSEE in 1930, his MS in 1931, and his PhD in 1933. In 1962, the University of Wisconsin awarded a Distinguished Service Citation to Dr. Brown for his leadership in industry and engineering. In 1933, Dr. Brown joined the RCA Manufacturing Co. in Camden, N.J., as a research engineer. In 1942 he transferred to the new RCA Laboratories research center at Princeton, N.J. During World War II, Dr. Brown was responsible for important advances in antenna development for military systems, and for the development of radio-frequency heating techniques. He and his associates also developed a method for speeding the production of penicillin. At the end of the war, Dr. Brown received a War Department Certificate of Appreciation "for his outstanding work in the research, design, and development of radio and radar antennas during World War II." From 1948 to 1957, Dr. Brown played a leading part in the direction of RCA's research and development of color and UHF television systems. In 1952, he was appointed Director, Systems Research Laboratory, RCA Laboratories. In 1957, he was appointed Chief Engineer, RCA Commercial Electronic Products Division, Camden, and six months later, Chief Engineer, RCA Industrial Electronic Products. In 1959, he was appointed Vice President, Engineering, Radio Corporation of America, and became Vice President, Research and Engineering, in 1961. He was appointed to his present position in 1965. That same year he was elected to the Board of Directors of RCA. A prolific inventor, Dr. Brown holds 79 U.S. patents; he is included in American Men of Science. Dr. Brown is a Fellow of the IEEE and the American Association for the Advancement of Science, and a member of Sigma Xi, the Franklin Institute, and the National Academy of Engineering. He is a Registered Professional Engineer of the State of New Jersey.

the engineer into prominence nationally and often internationally. Most companies allow time for their engineers to attend professional meetings and to participate in professional affairs and events, often at substantial cost. This is part of his continued education and development which ought, in the long run, to be a satisfactory investment.

Any company that has prospered in business for several years has a corps of older engineers, usually near the top of the salary scale, who have avoided managerial duties or have failed to be selected. Such men represent a lot of valuable experience; they know how to do things; they can coach and encourage younger men; and they can otherwise do an undistinguished but valuable job. Many may never have published a technical paper, quite satisfied to work along year after year in a certain anonymity professionally. Some keep up their technology and some do not. One of the most demanding tasks of engineering management is to recognize the young dead wood as potential old dead wood and to do something about it before time runs out.

Industrial engineers usually have access to excellent company libraries that make relevant periodical and book literature available to those who try to maintain their professional competence or as reference material for their work. A wise manager will encourage his engineers to use library time as a means of continued personal development.

A CHALLENGE TO ENGINEERING MANAGERS

A major problem in large organizations is that of keeping top engineering managers up-to-date technically. The rapidity with which electronic technology advances makes it very difficult to even comprehend new technology without working directly in it. Yet decisions, appraisals, allocations of men and money to various activities under one's jurisdiction depend upon some knowledge of today's science and technology. The use of mathematics today in what we can call ordinary engineering is orders of magnitude greater than it was twenty years ago. Branches of mathematics are in common use today that were not taught to engineering students at that time. The engineer today depends more on computation than on laboratory tests. Years ago, the engineering laboratories had the immense machinery while the physicists worked on benches in corners. This has all changed and it is the physicists who have the immense machines while the electrical engineer needs less and less as his skill in computation increases. Digital-computers are his newer tools, augmenting the traditional slide rule.

NEED FOR CONTINUING EDUCATION

Almost every company has lectures and discussions that help engineers to keep abreast of special subjects. In the Radio Corporation of America, we are trying systematically to enhance the knowledge of engineering managers. It is often called a "retread" course, but its name is "Current Concepts in Science and Engineering." It is run as a formal school in business hours, led by selected university professors and RCA teachers. The course encompasses a total of 24 class days, extending over a period of ten months. Textbooks are supplied and homework assignments are given. Each class averages about fifty students. After an experimental period with a pilot class in 1964, it was extended to several locations because our plants are widely distributed. In this way, we believe our key engineering managers can better comprehend the rapidly changing foundations of our varied and technically oriented businesses. The spontaneous expressions of approval by those who have completed the courses indicates that our efforts were not in vain. In fact, the response to this program has led us to make plans to extend these teaching techniques in a somewhat different form to our graduate engineers who are not in the management ranks.¹

Because of our corporate interest in continuing education, we thought it appropriate to consult the patient concerning his prior exposure to the educational bug. As part of my corporate research and engineering staff activities, we publish a small monthly magazine called TREND (The Research and Engineering News Digest). Several months ago, we used TREND as a vehicle to ask our engineers what they thought of engineering education. Essays were solicited to answer the question "Are colleges doing a good job of educating engineers?" The answers were varied but interesting. About two out of three engineers felt that colleges are not doing a good job of educating engineers. One of the most frequently stated reasons for this feeling was the lack of well-rounded training. A number of responses said that engineering schools were not putting enough emphasis on the humanities, social sciences, and liberal arts. Several writers discussed the conflict between specialized and basic training. Many felt that it was the industry's responsibility to provide the specialized training after the engineer had learned his fundamentals in the colleges. Several suggested that the undergraduate training should be extended to five years.

ENGINEERS CAN AND DO COMMUNICATE

Through all the responses ran the charges that engineers are not taught to communicate, that is, to speak and to write. Many engineering schools do have courses aimed at resolving these defects. I have often heard categorical statements to the effect that engineers do not know how to write. I only agree with this flat statement to the extent that I also believe most other people do not know how to write. But I also believe that for those people who can be taught to write the teaching must be done in the grade schools or high school. If this is not done, it is too late. In reviewing the essays, I was interested to observe that those who complained because the engineering schools were not teaching engineers to write and to express themselves voiced their complaints in very readable and sometimes elegant prose.

I have read innumerable papers and reports during my professional career, efforts of engineers and of other people, and I agree with my fellow engineers that the English language suffers at the hands of hosts of people. But I have here with me today a piece of writing by an eminent engineer, Herbert Hoover, which I have treasured for years for its clarity of expression, its pungency, and its thoughtfulness. It seems appropriate to share his words with you.

"The great liability of the engineer compared to men of other professions is that his works are out in the open where all can see them. His acts, step by step, are in hard substance. He cannot bury his mistakes in the grave like the doctors. He cannot argue them into thin air or blame the judges like the lawyers. . . . He cannot, like the politicians, screen his shortcomings by blaming his opponents and hope that the people will forget. On the other hand, unlike the doctor, his is not a life among the weak. Unlike the soldier, destruction is not his purpose. Unlike the lawyer, quarrels are not his daily bread. To the engineer falls the job of clothing the bare bones of science with life, comfort, and hope. No doubt as years go by, people forget which engineer did it, even if they ever knew. . . . But the engineer himself looks back at the unending stream of goodness which flows from his successes with satisfactions that few professions may know."

1. J. Wentworth, "Current Concepts in Science and Engineering," *this issue of the RCA ENGINEER*.

CURRENT CONCEPTS IN SCIENCE AND ENGINEERING

An Engineering Project in Continuing Education

The great majority of the projects reported in the pages of the RCA ENGINEER relate to "hardware" developments undertaken as part of the company's efforts to serve its commercial or government customers. This article describes a "software" project undertaken primarily to meet the professional-development needs of an important group within RCA itself. Current Concepts in Science and Engineering (CCSE) is a program of continuing education that has already served more than 400 RCA engineering managers and leaders. Development of this program has been one of RCA's major endeavors in the field of education; the final program embodies a number of unusual concepts and educational techniques that should be of interest to all RCA engineering personnel.

JOHN W. WENTWORTH, Mgr.

*Engineering Educational Programs
Product Engineering, Camden, New Jersey*

VERY few practicing engineers need to be reminded of the "knowledge explosion" that has taken place in our profession since World War II. Even a casual reader of the RCA ENGINEER must be aware that many of the developments described in recent issues of this journal are based on concepts that were virtually unknown as recently as ten years ago. The present pace of technical progress suggests that at least as many advances will be made during the coming decade as during the last. One by-product of this knowledge explosion in technology has been a recent upsurge of interest in *continuing* education for engineers and their managers. It has become almost self-evident that no engineer can hope to keep up with his profession by applying only the knowledge he acquired while earning his baccalaureate degree—he must continue to learn through experience and through participation in formal educational programs or through self-guided study.

RCA, like most modern employers of engineers and scientists, has long recognized an obligation to participate in the professional development of its personnel. The Corporation has played an active role in continuing education for many years through such activities as the Graduate Study Program, the Tuition Loan and Refund Plan, and the after-hours courses sponsored by the Company at most of its engineering locations. By 1963, however, the people most

Final manuscript received June 23, 1967

directly concerned with professional development within RCA felt that the problems of continuing education had intensified to the point where major new programs should be initiated to meet the growing needs. There was particular concern about educational opportunities in the technical area for engineering managers and leaders, who have special needs that were not being met by any of the existing programs.

In comparison with the engineers performing specialized tasks under his direction, the manager or leader needs technical knowledge characterized by *breadth* rather than *depth*. Conventional graduate-level courses, oriented to the needs of young people still working toward advanced degrees, are not well suited in either content or teaching methods to the needs of engineering management. The typical manager or leader has accumulated at least 10 years of experience since he left the university, and has become so preoccupied with administrative problems that he is hard-pressed for time to maintain his mathematical skills and to undertake purely technical studies. (Few managers have the time, for example, to work in a formal sense toward advanced degrees.) In spite of these handicaps, members of engineering management must devote a reasonable fraction of their time to the problem of keeping themselves up to date if they expect to retain their competence to direct technical programs.

The CCSE Program described in this

article was developed primarily to meet the specific needs of RCA engineering management, but it is also intended to serve as a "proving ground" for the development of techniques suitable for other professional-development programs in the future.

BACKGROUND

The CCSE Program was conceived during 1963 through the combined efforts of professional-development specialists in Product Engineering and Corporate Staff Personnel. The author was appointed to direct the program in late 1963, and creation of the program was formally announced at a meeting of RCA chief engineers and other key engineering managers in November of that year. Representatives from each of RCA's major product divisions and operating units were invited to join a CCSE Planning and Coordinating Committee, which met several times during the first six months of 1964 to plan the program's objectives, format, and curriculum. Meanwhile, a CCSE Program Staff was formed by the appointment of two well-qualified instructors to work with the author as course-development administrators.

Because a number of new concepts were embodied in the initial plans for the CCSE Program, a decision was made to "field test" the program by operating a pilot class. With the help of the CCSE Planning and Coordinating Committee, a class of 28 students was organized to begin the program in September, 1964. These students represented most of the major product divisions, and were carefully selected to provide a range of age and experience that was reasonably typical of RCA's total engineering management population. The pilot class met at the Ivystone Inn in Pennsauken, New Jersey, for two days every two weeks between September, 1964, and February, 1965 (a total of 12 two-day sessions).

A number of changes were made in the CCSE Program based on the pilot-run experience, and three regular classes (serving 140 participants) were initiated during the 1965-1966 class year. Five additional classes with an enrollment of 240 students have been conducted during the 1966-1967 class year.

PROGRAM OBJECTIVES

One of the first activities of the CCSE Planning and Coordinating Committee was to draw up a formal statement of program objectives:

Current Concepts in Science and Engineering is intended to support the RCA engineering manager or leader in his efforts to:



JOHN W. WENTWORTH was graduated from the University of Maine with a BSEE degree in 1949, and joined RCA in July of that year. After several years of development and design work on color television studio equipment, he became Manager of TV Terminal Equipment Engineering, a position he held from 1953 to 1959. He then directed his attention to the field of educational technology, and served several years as Manager of Educational Electronics for the Broadcast and Communications Products Division. Teaching, writing, and lecturing activities were prominent throughout his career with the Broadcast Division. He developed and taught after-hours courses in color television engineering that were attended by several hundred RCA and NBC engineers; he authored numerous papers and a complete textbook on color television engineering; and he developed several courses for cus-

tomers training in television tape recording and other aspects of broadcast technology. In early 1964, Mr. Wentworth was appointed Manager of the "Current Concepts in Science and Engineering" Program, an RCA staff activity aimed at supporting engineering managers and leaders in their efforts to stay abreast of new and fast-changing technologies. His title was recently changed to that of Manager, Engineering Educational Programs in recognition of the fact that the scope of his position has been widened to embrace the development of additional programs of continuing education for RCA engineering personnel. Mr. Wentworth is a Fellow of the SMPTE, and holds memberships in Tau Beta Pi, Phi Kappa Phi, the Society of the Sigma Xi, and the IEEE. He is a Registered Professional Engineer in New Jersey.

- Update his technical knowledge.
- Recognize the major technical trends affecting RCA's business.
- Appreciate the significance of the major unifying concepts which are common to many scientific and engineering disciplines.
- Acquire greater knowledge of RCA resources, and widen his circle of acquaintances within RCA engineering management.
- Develop knowledge of and confidence in new engineering methods, especially those based on the use of computers.
- Strengthen his personal reading and study habits.

NOTEWORTHY ASPECTS OF THE CCSE PROGRAM

Educational programs with objectives similar to those of the CCSE Program have been established by several educational institutions (notably UCLA and the Polytechnic Institute of Brooklyn) and by several other industrial corporations. The CCSE Program differs from the other programs known to this writer in a number of important respects, however. Unusual and significant features of the CCSE Program include:

- Reliance on company resources.* While some use is made of college professors and other outside specialists, most of the teaching and planning load for the CCSE Program has been carried by RCA personnel. (Many other companies rely on universities to plan and operate continuing education programs of this magnitude.)
- Development by engineers and scientists.* The CCSE Program was developed not by people who had previously specialized in training development but by professionally qualified engineers and scientists with personal competence in many of the subject areas included in the cur-

riculum. The procedures used for developing the program were essentially the same as those used in carrying out engineering design projects.

Magnitude Related to Staff Size. Some of the well-publicized programs sponsored by other companies for the technical updating of their engineering managers have been designed to serve only one or two classes per year (perhaps 30 to 60 students). The CCSE Program has been designed to serve 240 participants at a time, even though the full-time staff consists of only four men and three secretaries.

Conservation of Student Time. The costs involved in operating the CCSE Program are distinctly different from those which apply to a conventional graduate school at a university. Because CCSE "students" are relatively senior people who have already advanced to management positions, salaries for time spent in attending classes represent a major part of the CCSE Program costs. (Student salaries exceed all other program expenses by a factor of about two.) Efficiency in the use of student time has, therefore, been given a great deal of attention in developing the program. The degree of preparation expected of lecturers is considerably greater than for typical university programs, and class schedules are arranged to minimize disruptive effects on the participants' normal work routines.

Visually-Oriented Teaching. As one means of maintaining high efficiency in the use of class time, great emphasis has been placed on the use of visual teaching aids, prepared in advance of the actual class sessions. The CCSE staff has developed methods for producing such visual aids (notably transparencies for overhead projection) with only modest expenditures of time and money.

Feedback and Evaluation Techniques. The CCSE Program is dynamic in character; significant changes have been made in the program year by year in response to feedback data obtained from the students through systematic evaluation procedures.

CHARACTERISTICS OF CCSE PARTICIPANTS

It has already been noted that participants in the CCSE Program differ in a number of important respects from typical graduate students. Data abstracted from the registration forms for CCSE. Classes 1 through 8 (approximately 400 participants) are summarized below:

<i>Occupation at Time of Enrollment</i>	
	<i>% of all Participants</i>
Managers	52.5
Leaders	32.4
Others (mostly Staff Engineers)	15.1

<i>Educational Background</i>	
No Formal Degree	4.4%
Highest Degree: B.S.	61.4%
M.S.	30.0%
Ph.D.	4.2%

<i>Years of Experience since Baccalaureate Degree</i>	
10 or less	4.8%
11-15	25.1%
16-20	36.6%
21-25	15.6%
26-30	10.3%
30-35	4.8%
36 or more	2.8%

Note: Median age of CCSE participants to date is 39 years; median number of years since first degree is 17.

A few comments may be in order about some of the more subjective aspects of the CCSE student population. The great majority of CCSE participants have abandoned any interest they may once have had in working toward advanced degrees, but the author has found them to be highly motivated students; they appear to be eager to learn about new concepts in science and technology. (As a general rule, engineers who have advanced into management ranks demonstrate high motivation for most tasks they undertake.) CCSE students are keenly aware of the value of their own time, and are generally under very great pressure to use this time efficiently. While technical concepts are important to the participant, he typically spends most of his time on non-technical problems; he can spare time for the detailed study of new technical topics only if he anticipates some application of such topics to his work. With respect to

Informal lunch-time conversation helps managers and leaders to become better acquainted.



"creature comforts" and classroom procedures, the participant expects to be treated with reasonable deference to the professional status he has earned as an engineering manager or leader.

PROGRAM FORMAT

Participants are organized into classes that have ranged in size from 32 to 55 students. Each class meets for twelve 2-day class sessions, which are held at 3-week intervals throughout an academic year. Five of the eight classes completed to date have been operated at the Cherry Hill Inn in Cherry Hill, New Jersey; two have been located on the campus of Purdue University at West Lafayette, Indiana, and one was operated at the Molly Pitcher Inn in Red Bank, New Jersey.

The decision to base the CCSE Program on a total of 24 class days was made as a "design choice" while the program was in an early planning stage. The decision has proved to be quite sound—the 24 days provide enough time for adequate treatment of a wide range of concepts, while the total time diverted by each student from his routine activities remains within reasonable limits.

The possibility of scheduling classes for periods of a week or more at a time was given serious consideration, but was rejected in favor of 2-day class sessions for the following reasons:

- 1) Managers can "break away" from normal business much more easily for 2-day periods than for periods of a week or more.
- 2) There was a feeling that senior people with rusty study habits might reach a "saturation limit" on their learning curves after more than two days of intensive, fast-paced instruction.
- 3) Intervals of a few weeks between class sessions make possible the systematic use of reading assignments and other "homework" for the participants. Deliberate scheduling of the program over an academic year increases the total time that each student can reasonably be expected to invest in the program.
- 4) Intervals of a few weeks between class sessions also provide opportunities for the program staff to make revisions and adjustments in the program in response to the actual needs of the students as discovered during the early sessions.

It was originally planned to hold class meetings at monthly intervals, but experience with the accelerated pilot class (based on class sessions at 2-week intervals) indicated that 3-week intervals would provide better retentivity between sessions while still providing adequate time for homework assignments. The use of 3-week intervals makes it unnecessary to schedule classes during the summer vacation months, but still permits

simultaneous operation of as many as six classes by the limited CCSE Program staff. (Multiple class groups are scheduled on a staggered basis, using both Monday-Tuesday and Thursday-Friday sessions.)

Although participants from the Camden-Moorestown area have been able to attend classes at the Cherry Hill Inn while living at home, approximately one-half of all CCSE students to date have found it necessary to travel moderate distances and to remain overnight at the training center location during each class session. From an educational point of view the more distant students have found the inconvenience of travel more than compensated for by the benefits of greater isolation from the normal pressures of the office. Lunches for the class group on each meeting day are considered an important part of the CCSE Program. Participants are seated in groups of eight at small tables, and the informal lunch-time conversation helps the managers and leaders to become better acquainted with each other and to share information on topics of mutual interest.

CURRICULUM DEVELOPMENT

Subject matter for the CCSE Program is organized into five basic courses, which are conducted in parallel throughout the program. Titles for the five courses are: *Modern Physics, Semiconductors, Electronics Engineering, Computers and Their Utilization, and Applications and RCA Programs*. One or two topics from at least four of these five courses are developed during each session; students seem to welcome the changes in pace provided by moving from one subject area to another during a class day.

Modern Physics receives major emphasis in the CCSE Program because it provides the foundation essential for understanding current and future developments in materials and electronic devices. An objective of the physics course is to enable each manager or leader to "talk the same language" as the younger men who join RCA's engineering groups each year. The teaching of college physics has changed significantly during the past fifteen years. Emphasis has shifted away from Newtonian mechanics and macroscopic phenomena toward quantum mechanics and phenomena at the atomic and subatomic levels. The senior technical man has usually become familiar with some of the new concepts through reading and discussions with his colleagues, but he lacks the thorough understanding that comes from pursuing a well-organized course of study.

The *semiconductors* course provides greatly expanded treatment of one sub-

ject in modern physics that is of particular importance to RCA engineers and scientists. Theoretical material on semiconductor physics is supplemented by practical information on junction diodes, transistors, thyristors, tunnel diodes, injection lasers, and other semiconductor devices.

In the *electronics engineering* course, primary emphasis is placed on the newer techniques which have become important to RCA during the past decade or so. Digital computers are singled out for special attention because of the growing importance of the computer as an essential engineering tool in all disciplines. Material is presented both on the fundamentals of computer technology and on basic programming techniques. FORTRAN is taught by a workshop method; the participants actually write FORTRAN programs (ranging in complexity from simple tables up to procedures for solving differential equations) which are run off on a computer during the intervals between class sessions.

The course on *Applications and RCA Programs* provides opportunities to present topics which illustrate practical applications of concepts presented elsewhere in the program, and also serves to acquaint the participants with major engineering programs currently in progress throughout the Corporation.

The present curriculum plan for the CCSE Program as described above is the product of an evolutionary process. For the pilot class, an attempt was made to arrange the subject matter around a single theme as a means of emphasizing the basic unity of modern science and technology. The theme selected was "Information Handling", since almost every aspect of RCA's business is related in some way to the handling of information — its origination, acquisition, transduction, processing, recording, retrieval, transmission, or reception. The basic curriculum plan for the pilot program is shown by the following outline of session titles.

- 1) Systems Principles;
- 2) Energy Conversion and Transducers;
- 3) Signal Handling (two sessions);
- 4) Information Storage and Transmission;
- 5) Components, Devices, and Materials;
- 6) Modern Physics (two sessions);
- 7) Contemporary Science; and
- 8) Tools and Techniques of Modern Engineering (three sessions).

An objective of this plan was to sustain student interest by working progressively from systems concepts toward equipment and circuit concepts, thence to components, devices, and materials, and

finally to the underlying science which accounts for device behavior and the properties of materials. This topic arrangement may have been sound in theory, but it created problems in practice for two basic reasons: 1) it required a great deal of effort on the part of lecturers and staff members to coordinate the individual topics effectively with the central theme, and 2) the students found it difficult to absorb unfamiliar subjects in the concentrated doses made necessary by the serial approach. Consequently, a decision was made to abandon the use of a single theme in favor of a parallel approach in which the curriculum is organized around five separate themes.

During the first regular class year (1965-66), the five course themes were physics, mathematics, electronics, computers, and applications. In revising the program for the 1966-67 class year, the theme on mathematics was dropped in favor of expanded treatment of semiconductor concepts. The few mathematical topics still retained in the ccse Program are treated in the context of the fields in physics or engineering where the mathematical concepts are needed. (For example, the rudiments of vector analysis are covered as part of the treatment of electromagnetic theory.)

FACULTY AND STAFF DEVELOPMENT

During the pilot-run phase of the ccse Program, the full-time staff consisted of only three men (and two secretaries), and most of the teaching was done by RCA specialists recruited for specific lecturing assignments from the RCA Laboratories or the product divisions. The pilot program "faculty" consisted of 49 people, all but 9 of whom were RCA employees.

As the program matured, staff members have taken on more and more of the teaching load, reducing their dependence on other RCA specialists and outside lecturers. During the 1966-67 class year, for example, the three academically-qualified members of the program staff presented slightly more than

50% of the lectures, and the total faculty consisted of 28 people. In the present version of the curriculum, there are 5 topics that are presented primarily through the use of films, rather than "live" lectures. (Many other films are used in a more incidental way for portions of complex topics.)

The full-time ccse staff now consists of seven people, classified as follows: one manager, one administrator for program services, two course development administrators, and three secretaries. The administrator for program services (G. B. DiGirolamo) assists in the preparation of budgets and schedules, and is directly responsible for all physical arrangements related to the class sessions. The two course administrators (Dr. Gary D. Gordon and Dr. Louis Shapiro) are responsible both for teaching specific topics in the program and for recruiting and counseling other faculty members. As manager of the program, the author finds it necessary to spend most of his time on administrative matters, but still finds opportunities to participate to some extent in the teaching activity.

EDUCATIONAL METHODS, FACILITIES, AND MATERIALS

To a superficial observer, the educational methods used in the ccse Program may appear quite conventional, but the degree of preparatory work behind each class session is far greater than in most university courses. The program is based on a combination of class work and outside study assignments. Class activities include lectures, films, class discussions, and occasional workshop periods. The student is expected to prepare himself for each class session by reading study guides and text assignments related to the topics to be discussed, and is encouraged to "follow through" after each session by working on a group of carefully selected homework problems. (About 50% of the participants have actually made systematic use of the homework assignments.) All activities are carefully planned to make effective use of the student's time.

The classroom facilities available for an educational program play an important role in shaping the teaching techniques. Although ccse classes are operated in many different types of rooms (mostly in commercial hotels or motels), a standard "package" of classroom equipment has been assembled for use at each class location. The "package" includes an electronic lectern, two overhead projectors, a motion-picture projector, slide projectors for both 2-by-2-inch and 3¼-by-4-inch slides, 2 or 3 projection screens, an audio tape recorder, and a Thermofax copier. The traditional blackboard has been abandoned as a teaching aid for ccse classes, primarily because it is not satisfactory for use before large class groups of 30 to 50 students seated at tables which provide adequate space for books and working papers. A modern substitute for the blackboard (and one that is far more versatile) is the overhead projector equipped with a continuous roll of clear acetate film.

At the teaching position in each ccse classroom, the electronic lectern (which provides suitable sound amplification for guest lecturers untrained in voice projection techniques) is flanked on each side by an overhead projector. Two screens for these projectors are arranged behind and slightly to each side of the lecturer; the screens are placed at slight angles to the front wall of the room so that the images have little keystone distortion. Most experienced ccse lecturers have learned to employ both screens at once, keeping visual reference material on one and developing fresh material on the other. Virtually anything that can be done at a blackboard can also be done on the overhead projector by writing or sketching with a nylon-tipped pen on the acetate roll covering the 10-by-10-inch projection aperture, and a great deal of class time can be saved by the use of pre-prepared 8-by-10-inch transparencies. In some of the ccse classrooms, a third screen is used in the center of the room for slides and motion-picture material; in other rooms where the use of a center aisle is not practical, the slide and motion-picture projectors are located at one side of the room where they can project images to one of the same screens used for overhead projectors. As noted previously, extensive use of visual aids is a vital factor in maintaining high efficiency in the use of class time.

Effective visual aids in the form of 8 x 10-inch transparencies are remarkably easy to prepare with modern tools and facilities. The primary reason for

Dr. G. Gordon of the electronic lectern with overhead projectors on either side.



providing a Thermofax copier at each CCSE classroom is to permit "on the spot" production of transparencies from material that has been typewritten or hand-drawn with nylon-tipped pens on ordinary sheets of 8½ x 11-inch paper; such transparencies can be made in only a few seconds. Additional facilities for use by CCSE staff members at the "home office" include a special typewriter for producing quarter-inch-high letters, templates for the rapid production of simple sketches, and a "Headliner" instrument for producing lettering in a variety of type styles and sizes. Several different copying processes are also available for piecing together visual materials from a variety of sources.

The audio tape recorder for each CCSE classroom is connected to the electronic lectern. This recorder is used primarily for quality-control purposes (to be explained presently), but is also available for occasional use in playing pre-recorded tapes through the loud-speaker in the electronic lectern.

Learning aids for CCSE students include approximately a dozen textbooks (several of which are in paperback form) and study guides which cover in written form essentially the same material presented by each lecture. The study guides are normally distributed in advance of each class session for preparatory study, and serve as permanent notes for the student. A complete set of study guides for the CCSE Program consists of approximately 1600 pages. A policy decision was made at an early stage in the program development to limit the distribution of study guides to actual CCSE participants — the study guides are not intended to stand alone, and are effective only when used in conjunction with the related lectures. Special packages of review materials in physics, mathematics, and basic electronics are mailed to each registered CCSE student at intervals during the three months prior to his first class meeting.

QUALITY CONTROL TECHNIQUES

Considerable emphasis has been placed on quality control throughout the history of the CCSE Program, and it is probably in this area that the Program differs most significantly from ordinary university programs. The pilot run was undertaken primarily as a quality-control measure, and other techniques are used systematically to monitor the quality and effectiveness of the program.

One important safeguard in the development of any educational program is the preparation of formal statements of objectives, both for complete courses and for individual topics. Early in the

CCSE program, the staff found it necessary to rely rather heavily on the judgment on non-staff lecturers regarding learning objectives and subject-matter arrangements of individual topics, and some of these lecturers were quite unfamiliar with systematic approaches to the development of educational material. As the program matured, however, the staff has become increasingly confident about its understanding of student needs and its ability to specify in advance the objectives of individual topics. Lecturers are expected to submit drafts of study guides well in advance of their class appearances so that they can be edited, reproduced, and distributed to the students before the class session. Editorial review of these study guides gives CCSE staff members opportunities to estimate how well course objectives will be met and to suggest changes in emphasis when appropriate.

"After the fact" quality control tools include audio tape recordings and evaluation forms filled out by the students. Audio recordings are made of nearly all activities in CCSE classrooms.

Many of the recordings are never actually used, but it is possible for the staff to refer back at any time to the actual events of a class session as an aid in planning course refinements. Some lecturers have requested opportunities to replay their own tapes as a means of self-evaluation. In a number of instances, study guides have been prepared by CCSE staff members from transcriptions derived from the recordings of outstanding lecturers. (Some teachers prove to be far more effective as lecturers than as writers.)

All CCSE students are asked to fill out evaluation forms at the completion of each 2-day class session, indicating their overall rating of each topic (on an "Excellent—Good—Fair—Poor" scale) and explaining their rating in a sentence or two. Because of the diverse backgrounds of the students, they are asked to sign the forms so that their comments can be properly interpreted. Most students have accepted this evaluation procedure in a highly constructive spirit, and the CCSE staff has found the "feedback data" from this source extremely useful.

At the completion of the entire program, students are asked to complete a somewhat more comprehensive evaluation form that solicits their opinions about the program as a whole. Such "end of course" evaluation data has been very helpful in planning improvements for the program between class years.

Evaluation techniques used in the CCSE Program may appear to be a reversal of normal educational procedures.

Instead of periodic quizzes and exams to measure the performance of *students*, there are evaluation forms by means of which the students regularly measure the performance of *instructors*. Upon closer examination, however, it quickly becomes apparent that the evaluation procedures are not intended to make the CCSE Program an endurance contest or an obstacle course for instructors, but are intended to make sure that the Program continues to operate for the benefit of the students.

The results of the CCSE Program are difficult to measure precisely, since many of the benefits to the students are long-term and intangible. Staff members occasionally receive reports which indicate that the CCSE Program has been rather directly instrumental in shaping a design choice or a decision to go after a specific contract. In general, however, some of the better indicators of the program's effectiveness are the attitudes and the attendance records of the students. As indicated previously, the CCSE participants have keen appreciation of the value of their own time, and their attendance at CCSE classes is voluntary. It is significant, therefore, that the average attendance is about 85%, that many of the absences are "made up" by attending the missed sessions with a different class group, and that the students appear to be quite enthusiastic about their experiences with the CCSE Program. It is also noteworthy that the 240 registrations for the 1966-67 class year were obtained with virtually no promotional effort other than the "word of mouth" promotion undertaken voluntarily by former participants.

FUTURE OUTLOOK

In accordance with the original "master plan", the CCSE Program will probably be operated for only one more year (1967-68) in its present format. The CCSE staff has recently accepted an assignment to develop a new and somewhat larger-scale program to serve both supervisory and non-supervisory engineers throughout RCA. Because RCA's engineering population is widely distributed across the country, extensive use will be made of a variety of approaches to educational technology in this new program as means of providing uniform, quality-controlled instruction at all RCA engineering locations. Most of the course material prepared for the CCSE Program will be re-processed into new formats suitable for the new program, and a great deal of additional material will be developed to provide good continuing education opportunities for all RCA engineers.

SPACE ACTIVITY IN CANADA

The investigation of space, and the exploitation of it for the betterment of man, has occupied the attention of increasing numbers of scientists, engineers, lawyers, politicians and others not only in the United States of America and the U.S.S.R. but throughout the world. In Canada, the Engineers at RCA Victor Company, Ltd., have supported such space programs as RELAY, ALOUETTE, and ISIS with equipment and detailed studies. They have also designed and built Communications Satellite Earth Stations, and are presently competing with several other companies to obtain a solid position in the world market for these stations.

G. B. MacKIMMIE, Mgr.

Space Systems

J. A. COLLINS, Mgr.

Space Systems Marketing

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CURRENT SPACE ACTIVITY can be divided into two broad classifications: (1) investigation and exploration of the space environment including the reactions of men and materials to it, and (2) the use of space to serve man's immediate needs. This paper and several of the following papers describe work being done by RCA Victor Company, Ltd., Montreal, Canada under both of the above classifications.

HISTORY OF RCA VICTOR SPACE ACTIVITY

Under the heading of investigation and exploration of the space environment, Canadian scientists had, even before the advent of orbiting satellites, attained a position of leadership in ionospheric studies. The ionosphere is a logical subject of specialization for Canada because of its proximity to the *Aurora Borealis* an important phenomenon associated with the ionosphere. Furthermore, Canada, because of its sparse population and vast area, has a great need of reliable and inexpensive communications, the future development of which may well depend on increased knowledge of the ionosphere. Out of this interest and background, the ALOUETTE project was born in 1959. Canada took advantage of an offer by the U.S.A. to provide launch facilities for ALOUETTE I, the first of a series of Canadian ionospheric sounding satellites, and a forerunner of ALOUETTE II and ISIS A. ALOUETTE I and ALOUETTE II, launched in 1962 and 1965 respectively, have been outstandingly successful satellites. ISIS A is to be launched in 1968.

RCA Victor first became involved in the ALOUETTE-ISIS program when the Government Laboratory constructing the satellite sought and obtained assistance in supplying an FM telemetry transmitter

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for ALOUETTE I. This first order led to a subsequent contract, calling for progressively increased participation and responsibility on the part of RCA Victor for the ALOUETTE-ISIS program and its hardware.

Falling under the heading of serving man's immediate needs comes the subject of Communications Satellites, with their associated Earth Stations and terrestrial interconnections.

Studies during the 1950's culminated in the decision by NASA to construct the RELAY experimental communications satellite, intended to establish the feasibility of satellites for transatlantic transmission of wideband message traffic and television. RELAY I was launched in December, 1962, and after a difficult beginning, became a great success. RCA Victor, Montreal, held a subcontract from the Astro-Electronics Division, Princeton, N.J., for the development and construction of the all-solid-state transponder for the RELAY satellite.

While the work was proceeding at AED and at RCA Victor on the RELAY project, senior officials of Government and the Communications Industry were busily working on a bill which was subsequently passed by Congress and became known as the "Communications Satellite Act of 1962." The aim of this act is lucidly expressed in one of its opening paragraphs:

"The Congress hereby declares that it is the policy of the United States to establish, in conjunction and in cooperation with other countries, as expeditiously as practicable a commercial communications satellite system, as part of an improved global communications network, which will be responsive to public needs and national objectives, which will serve the communications needs of the United States and other countries, and which will contribute to world peace and understanding."

One result of the Communications Satel-

lite Act of 1962 was the creation of the Communications Satellite Corporation (COMSAT), whose purpose it is to implement the policy defined in the Act. International cooperation and participation was arranged through the formation in July 1964 of INTELSAT. Nineteen countries were original signatories to the IntelSat agreement, amongst which was Canada with a 3.75% interest. COMSAT became INTELSAT's manager for the space segment (the satellites).

While INTELSAT was being formed, Canada took the decision to proceed with the construction of an experimental Communications Satellite Earth Station originally intended to participate in NASA's Applied Technology Satellite program. RCA Victor received a work definition contract in the summer of 1963 for this station and shortly thereafter a contract for the supply of the station itself.

Thus, by late 1963, RCA Victor was solidly into a scientific space program, ALOUETTE-ISIS, and a Communications Satellite program—Canada's Earth Station at Mill Village. These contracts were won only by demonstration of engineering competence in such specialties as wideband microwave communications technology, RF optics of large antennas (including feed systems), and systems engineering. This competence grew out of earlier in-house development work in microwave radio relay, and work done under various NASA or NASA-sponsored projects. Furthermore, RCA Victor Research Laboratories had been active in many areas of space technology, and was ready to support the engineers as required.¹

DESCRIPTION OF PRESENT PROJECTS

International Satellites for Ionospheric Studies (ISIS)

The third satellite of the ALOUETTE-ISIS series of ionospheric sounding satellites, ISIS A, is now under construction at RCA Victor. As is the case for ALOUETTE I and II, the principal experiment aboard ISIS A is the ionospheric sounder. Sounding is accomplished by a pulsed swept-

L. A. Keyes and H. Hore inspecting engineering model of ISIS A.





G. B. MacKIMMIE received the B. Eng. (Communications) degree from McGill University in 1943. In 1945, after two years with the Royal Canadian Navy as an electrical officer, he joined RCA Victor where he was engaged for several years in the field of antenna design. From 1956 to 1958 he was Manager of the Broadcast and Antenna group in the Engineering Department. From 1958 to 1960 he was Manager of the Engineering Department, Technical Products Division, and between 1960 and 1966 Mr. MacKimmie was Chief Engineer of Technical Products. In 1966 Mr. MacKimmie was appointed Manager of Space Systems of RCA Victor



Company, Ltd. The activity of Space Systems encompasses the development and supply of communication satellite earth stations for the global market and of scientific satellites and subsystems thereof. Mr. MacKimmie is a member of the Corporation of Engineers of Quebec.

J. A. COLLINS received the B.Sc. Degree from the University of British Columbia in 1942. He joined RCA Victor in the same year and for a period of seven years was engaged in various design, development programs covering high power LF transmitters, multiplex equipment and instrument landing systems. For two years he served with the

Broadcast Engineering group on design of antenna matching networks and installation and proof of performance of broadcast transmitters across Canada. In 1951, Mr. Collins was transferred to Marketing operation of Technical Products for the company, in which capacity he handled sales of radio relay systems, mobile radio, and special defence projects. In 1952 he was loaned to the newly formed Department of Defence Production in Ottawa as a production officer to assist in the military preparedness program, which embraced the Mid-Canada Early Warning Line, the Pinetree Line, and a total step-up in Canada's defence efforts. Upon his return to RCA Victor in 1954, he served as manager of Government Contracts Department. He was actively associated with the ASTRA weapons system contract for the CF-105 project, other major projects, and the build-up of research and development capability within the company. In 1966, Mr. Collins assumed the position of Manager of Marketing for the newly formed Space Systems operation of Technical Products. He was instrumental in bringing about the build-up of capability for communication satellite earth stations. He is currently involved in studies of the application of satellites to serve Canada's growing requirements for Educational TV, Broadcasting, and general Communications.

frequency signal of 100-microseconds duration and 400-watts peak power. The frequency coverage is from 0.1 MHz to 20 MHz. The swept frequency system is supplemented by a fixed frequency sounder operating at six selected frequencies between 0.25 and 9.3 MHz.

A unique feature of the Isis A satellite is the long antenna associated with the sounder experiment. Two dipoles, one having a length of 240 feet and the other a length of 61½ feet, are used to cover the complete frequency band. The dipoles are extended from the spacecraft when in orbit and, in space, are self-supporting.

Other experiments carried aboard Isis A are:

- VLF, to measure incidence of lightning induced waves (whistlers) at very low frequencies;
- Cosmic Noise;
- Energetic Particle Detector;
- Langmuir Probes, to measure electron density;
- Ion mass spectrometer;
- Ion probe, to measure ion density;
- Soft Particle Spectrometer;
- Beacon, to measure scintillations, particularly in the auroral zone.

The Isis A satellite will carry a tape recorder for data storage: a new feature not provided in its predecessors. An engineering model of Isis A has undergone complete electrical tests, and the flight-unit structure has been fully tested and approved. Flight unit electrical subsystems are now being assembled and engineers are, at the time of writing, beginning the integration of hardware onto the flight structure. At present, approximately forty RCA Victor Engineers with supporting staff are engaged in this activity.

Communications Satellite Earth Stations

Following the successful completion of Canada's experimental Earth Station, a second station was needed for handling commercial transatlantic traffic at the same location. Accordingly, the Canadian Overseas Telecommunications Corporation solicited international tenders in late 1966, and after evaluation, chose RCA Victor as the supplier. The design of the new earth station differs from the completed experimental one in the following main respects:

- No radome is used;
- Antenna diameter will be 95 feet;
- The interconnection between antenna and control building is accomplished at 4 and 6 GHz, instead of at baseband or video frequencies; and
- The station will be equipped for simultaneous reception of nine separate RF carriers and transmission of two carriers.

Both stations are equipped with automatic tracking antennas which can lock on medium altitude as well as synchronous satellites, although for the immediate future only synchronous satellites will be available for commercial traffic.

In addition to the work which is now beginning on Canada's commercial earth station, Engineers at RCA Victor are busy proposing similar stations to other countries. The international bidding for earth stations is highly competitive, with the leading companies eagerly seeking to obtain a solid position in what undoubtedly will become a substantial market in years to come. RCA Victor Engineers have recently lent assistance to RCA Communications in the establishment of the latter's temporary earth station in Thailand.

THE FUTURE

In Canada, the direction of space activity during the next ten years might well be towards the employment of satellites for tv and telephone service to the north-land, for augmenting existing east to west communication facilities, and for educational tv (a particularly attractive application considering Canada's scattered rural population).

A fundamental question which must be resolved is whether Canada should own synchronous satellites for expansion of its domestic communications, or whether it should rely on renting circuits from a satellite system which is owned by International or U.S.A. interests. In either event, Engineers at RCA Victor look forward to active participation in whatever program is chosen to serve Canada's domestic needs.

As far as programs outside Canada are concerned, it is hoped that there will be a continuation and growth of the kind of cooperation with other parts of RCA which led to the highly successful RELAY I and II satellites. Space communications, by its very nature, extends far beyond national boundaries. The opportunities for service to mankind in this field are unlimited for those who by training and experience can make useful contributions. It is hoped that Canadian Engineers, along with those of the U.S.A. and other nations, will make the best of these opportunities.

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SYSTEM DESIGN AND RELIABILITY CONSIDERATIONS FOR THE ISIS A SPACECRAFT*

The purpose of the ISIS A satellite is to provide data which will aid in the solution to the problem of radio-wave propagation in the upper atmosphere; the main experiments are topside ionospheric sounding with VLF and VHF equipment and direct particle samplings made within one meter of the spacecraft. The choice of such satellite subsystems as telemetry, power, command, and attitude sensing and control are described. Reliability goals, and the means available to meet them, are discussed. A reliability flow diagram with estimated yearly failure rates is developed showing unit and system redundancies from which satellite mission success probabilities are calculated.

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THE ISIS A spacecraft will be the second of four satellites used in a program of upper-ionospheric measurements sponsored jointly by the Canadian and United States Governments. The National Aeronautics and Space Administration (NASA) Goddard Space Flight Center is responsible for the launch, tracking, and data acquisition through the NASA STADAN network. The Defence Research Telecommunications Establishment (DRTE) of the Canadian Defence Research Board is responsible for the design, construction, and testing of the spacecraft as well as the control of the satellite and data acquisition from telemetry stations in Canada. RCA Victor Company, Ltd., Montreal, is the prime contractor and de Havilland Aircraft of Canada is the associate contractor for the spacecraft which will be launched by a Delta vehicle from the Western Test Range at Vandenberg, California.

The purpose of the spacecraft is to continue a series of topside ionospheric sounding begun by ALOUETTE I (1962) and ALOUETTE II (1965) and to complement this with simultaneous direct particle measurements within one meter of the spacecraft. The series of ISIS (International Satellites for Ionospheric Studies) satellites is planned to provide measurements over a large part of a solar cycle.

The 500-pound spacecraft has units mounted within and on a central thrust tube and equatorial panels (Fig. 1). The spacecraft is to be spin stabilized in a polar orbit with a 3500 km apogee and 500 km perigee.

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SYSTEM REQUIREMENTS

The ten complementary experiments on board Isis A largely dictate the system requirements. In these experiments, the composition of the ionosphere is examined using two methods: (1) direct measurement of the energy and flux of particles within one meter of the spacecraft and (2) remote measurement by swept-radar sounding techniques and by beacon observation. The data obtained are to be accurately correlated, in time, to other ground based observations.

The five direct measurement experiments are:

- 1) An *electron (Langmuir) probe* in which a slowly varying voltage is applied to two electrodes and the resulting volt-ampere curve is used to determine electron temperature and density.
- 2) A *spherical electrostatic analyzer probe* which applies a slowly varying voltage between concentric, spherical meshes. From the resulting current, information is gained about the energy and mass of the ambient ions.
- 3) An *RF quadrupole ion mass spectrometer* from which the charge-to-mass ratio of the surrounding ions (mass numbers from 1 to 20) is determined.
- 4) An *energetic particle detector* which is capable of measuring energies from 3 keV to 50 MeV. It consists of scin-

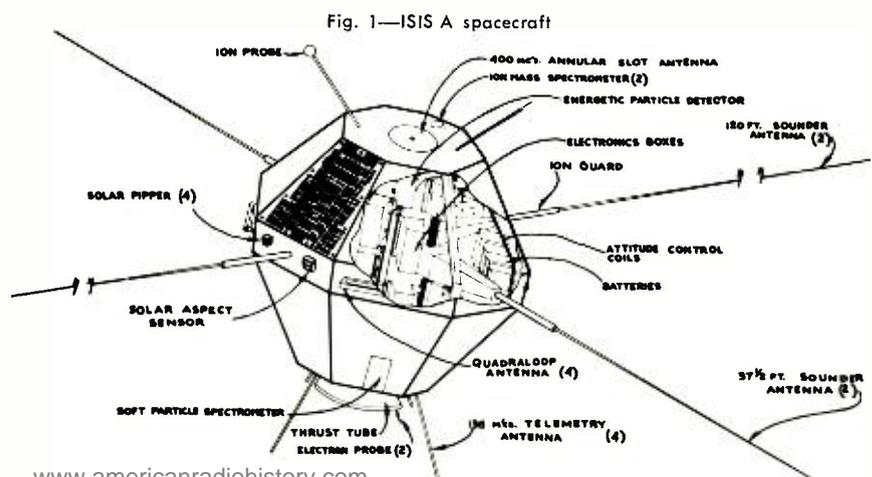
tillation counters, Geiger counters, and solid-state detectors.

- 5) A *soft particle spectrometer* measuring in the range from a few eV to 10 keV.

These experiments are supplied as packages ready for integration except for probe mounting and the necessary power, telemetry, and command inputs.

The remote experiments are:

- 1) A *swept frequency sounder* (the principal experiment) which is a pulsed radar system sweeping over the range 100 kHz to 20 MHz in about 30 seconds, transmitting a 100 microsecond pulse at 30 or 60 pulses/second. Energy is radiated and received by two sets of crossed dipoles: one set 240 feet tip-to-tip and the other 61.5 feet tip-to-tip. Echoes from the ionosphere as a function of frequency give a measure of ionosphere electron density from which ionograms or density profiles can be made.
- 2) A *fixed frequency sounder* which uses the same basic apparatus as the swept sounder to perform finer spatial resolution measurements at one of five fixed frequencies.
- 3) The *AGC voltage* of the sounder receiver which is used to measure cosmic noise as a function of frequency.
- 4) A detector, which is basically an *AGC audio amplifier*, is used to measure VLF radiations and whistlers in the range 50 Hz to 30 kHz. This detector





LORNE KEYES received the E.Sc. in Electrical Engineering from Queen's University in 1954. He has taken a number of graduate courses at McGill University. He has been employed at RCA Victor Company, Ltd., Montreal, since 1954 on a variety of telecommunication problems including airborne VHF transceivers, UHF troposcatter telephony, and heavy route microwave telephony. He was engaged in design and system integration of the NASA RELAY communications transponder and recently participated in communications satellite proposals to COMSAT Corporation. He is a member of the Quebec Corporation of Professional Engineers, the Engineering Institute of Canada and the IEEE. He is currently Spacecraft Systems Engineer for the ISIS A Program.

W. R. ATKINS received the B.Sc. in Electrical Engineering from the University of Alberta in 1956, and remained there the following year for post graduate studies while holding a lecturer's assistantship. He obtained an Athlone Fellowship to

is connected to one set of sounder poles and may also be used with a swept exciter to measure ion-resonance effects.

- 5) A VHF beacon propagation experiment which determines total electron content and scintillations in the ionosphere between the satellite and a receiving station.

Because coverage beyond that available in real-time telemetry and command is required, a tape recorder and a clock and programmer are included for remote control and data gathering. A minimum of four hours per day of sounding should be possible at the end of one year in orbit, and it should be possible to operate continuously for two consecutive pole-to-pole passes (half orbit) in the same direction.

The requirement for a reasonable probability of operation of the spacecraft for longer than one year is embodied in the spacecraft system reliability goals. The most important of these goals is a 0.8 or better probability (60% confidence) of completely satisfactory operation at the end of one year in orbit as based on 2000 hours of main mode operation during that year. (Completely satisfactory operation is defined as a fully operational condition in all equipment with the exception of an on-board tape recorder and certain non-essential monitoring channels, solar cells, and programming capability; only one of completely redundant equipments need work. Completely satisfactory operation is a much more stringent criterion than mission success, which is more difficult to specify.) Another important goal is that system design is to be such that the probability of a first failure causing the loss of useful data from more than three experiments should not exceed 0.05.



study in England for the period 1957 to 1959, receiving a Diploma from Imperial College and an M.Sc. from the University of London for work on transistor analog multipliers, and gaining experience in analog computers and transistor pulse circuitry. From 1959 to 1960, he was employed by Canadair working on pulse multiplexing equipment of quasi-static low-level information and environmental testing of transistor equipment. In 1960, he joined RCA Victor Research Laboratories, working on studies connected with radar under ECM conditions and investigating behaviour of noise at very low levels. In 1961, he was awarded a David Sarnoff Fellowship to proceed with his studies at the Imperial College of the University of London under RCA Corporate Sponsorship, receiving his Ph.D. in 1965 for work on sequential decoding techniques using decision theory. Since returning to the RCA Victor Research Laboratories, he has been advising on technical exhibits for EXPO '67, and more recently, concerned with spacecraft reliability and systems studies.

DESIGN APPROACH

Structure

For the required orbit, the Delta launch vehicle allows a payload weight of 500 pounds. Based on the limits of the maximum diameter inside the spacecraft shroud and the power requirement of 50 watts (average) body-mounted solar cell arrays were chosen instead of the mechanically more complex erectable-paddle arrays. The requirement for nearly equal power output at all solar aspects dictated the roughly spherical shape: this shape results in an average power output, for random spin-axis orientation, within a few percent of optimum and has satisfactory thermal and structural properties. The thrust-tube mounting of components provides good accessibility for test and installation, except for those mounted inside the tube. To maintain dynamic stability, it is necessary to locate some of the boxes on the equatorial panels, thus maintaining maximum moment of inertia about the spin axis. A principal feature of the mechanical design is the great length of the sounding antennae: 240 feet tip-to-tip for one set and 61.5 feet for the other. The large change in moment of inertia (as the pre-stressed tape antennae are extended) produces a despin from 90 r/min (at separation) to 3 r/min.

Thermal control is passive by choice of surfaces and by means of aluminized mylar heat shields which are placed over the ends of the thrust tube. Major heat flow is along the tube and the mylar blankets introduce a thermal resistance which reduces this heat flow and, as a result, reduces the temperature gradient along the tube. The high temperature extreme for end-on illumination and the

worst-case combination of a fully charged battery and full sunlight is $+40^{\circ}\text{C}$. The low temperature extreme of -5°C occurs for a discharged battery and end-on illumination in minimum sun (eclipse). The average temperature for random orientation varies by about 30°C . The thermal blankets are beneath the outer covering of the spacecraft which must appear as a closed electrically conducting sphere for RF continuity. The surface of the spacecraft must also present a minimum of 1000 square inches of free metallic area to satisfy experimenters needs.

The spherical electrostatic probe and one of the Langmuir probes are mounted on erectable booms at the top end of the spacecraft. This position is considered necessary to keep the probes from being influenced by the plasma sheath which forms around the spacecraft as a result of voltage induced in the sounder poles as they cut the earth's magnetic field ($V \times B$ effect). This sheath represents an equilibrium condition between the resulting collection of highly mobile electrons and less mobile ions.²

Telemetry

The choice of transmission bands is determined by compatibility with the existing 136-MHz and 400-MHz NASA STADAN facilities.

The sounder data in natural form is a composite video waveform consisting of calibration, synchronization and echo return pulses in a spectrum from DC to 20 kHz. This bandwidth makes PCM processing impractical. Although it contains much redundant information and could possibly be processed on board into a more compact form, the simple FM analog transmission system proven on ALOUETTE I and II was adopted. This system matches the existing facilities for ionogram preparation, 136-MHz transmission frequency, and 100-kHz channel bandwidth.

The VLF signals in the band from 50 Hz to 30 kHz are readily accommodated on the same transmission link either on a time-shared basis or by straight summation. The latter technique is possible because the sounder signals are analyzed mainly on a time-domain basis while the VLF signals are analyzed mainly in the frequency domain. The interfering sounder spectra which contains a large proportion of energy at harmonics of the pulse rate can be filtered out or largely ignored. Separate but simultaneous VLF and sounder can be transmitted at the expense of extra power consumption by putting the VLF on the 400-MHz link.

A standard 30-kHz IRIG FM subcarrier modulates the main carrier and is pulse-

amplitude modulated (PAM) by the output of a 30-channel essential housekeeping commutator. This is multiplexed with a pulse-width-modulated time code to satisfy a data processing requirement that spacecraft time be available on all data links. The PAM essential housekeeping system is used mainly by the satellite controller for quick-look monitoring of such essential parameters as battery currents and voltages, which are also carried on the PCM system.

Transmission of most direct particle measurement data could be accomplished simply either by an analog system of several FM subcarriers on a single carrier or by time multiplexing on a single carrier. However, due to the widespread use of the recommended NASA PCM time-multiplex system and the compatibility with present data processing systems, a PCM system was chosen. This system lends itself readily to various data rates by use of super- and sub-commutation but it necessitates complex synchronizing and decommutation equipment on the ground. The soft-particle spectrometer and the energetic particle detector have data in digital form which can be conveniently multiplexed into the bit stream. The format chosen is a 24-word frame 60 times per second using an 8-bit word. Quantizing errors are consistent with the 1 percent accuracy aim for the telemetry system.

Some data are sampled twice per frame (120 words/sec) while others are sampled once per second by one of two 60-channel subcommutators. The synchronizing pattern comprises the first 16 bits in a pseudo-random pattern. One bit of the frame carries time code in a non-standard 60 pulse/second BCD format; one bit carries the output of a 60-channel flag subcommutator.

The PCM transmission scheme is a split-phase format modulating a PM transmitter, as this system gives the minimum transmitter power (2W) for the marginal bit error rate of 10^{-4} . The modulation index is adjusted to leave ten to fifteen percent of the nominal power as a residual carrier to permit good carrier lock for coherent reception.

Transmitter powers and deviations are based on the principle of limiting marginal performance at maximum slant range. Assuming the lowest performance telemetry receiver system operating at 15-degree antenna elevation, marginally satisfactory ionograms can be made with a video S/N ratio of 20 dB.

For both FM and PM systems, average performance will be much better than the marginal limits, since marginal conditions occur for only a short time.

Both FM and PM transmitters are di-

plexed together and duplexed with the command receivers to feed a four-pole turnstile antenna symmetrically mounted around the bottom end of the satellite. This antenna produces an almost omnidirectional circularly polarized radiation.

The beacons radiate through four equatorially mounted quadriloop elements fed in quadrature to produce a nearly omnidirectional circularly polarized radiation pattern.³

The tape recorder requires four channels: two analog for the sounder and VLF, one digital for the PCM, and one analog for time code. The record and playback speeds are interrelated and are ultimately controlled by the bandwidth and power available for the replay link as well as by the time available for read-out. The 400-MHz band was the only feasible choice for the replay link and a 500-kHz channel with a transmitter power of 4 watts allows 65 minutes of recording and a 4:1 speed-up on playback. This permits a full tape dump on an overhead apogee pass. Normal record periods are 16 minutes, but successive record periods can cover a single pole-to-pole pass.

The 400-MHz link can also be used as a real-time back-up for the 136 MHz FM and PM. The 400-MHz transmitter has both FM and PM modulation capability. The sounder, or VLF signals, frequency modulate the carrier while a 93 kHz subcarrier normally carrying the PCM data, phase modulates the carrier. Time code in the form of amplitude modulation on a second subcarrier also phase modulates the transmitter. The transmitter radiates from an annular slot antenna, flush mounted at the top end of the satellite, thus there are no protrusions near the particle probes that might affect the plasma. Although it would have been desirable not to have any RF field in the region, it was not structurally feasible to put the antenna on the opposite end. In any case, the RF field produced probably has a negligible effect in comparison with the 400-watt sounder pulse. To provide some control of the plasma effect produced by the sounder poles near the spacecraft, loose insulating boots or sleeves are fitted over the first few feet at the base of the sounder poles.² A DC bias may also be applied to the sounder poles.

Command System

Based on the large number of experiments and the required operational flexibility, over 100 separate commands were needed. For compatibility, only NASA command standards were considered. A system that exceeds the 70-command capacity of the tone Digital System and

yet is simpler than the PCM Instruction Command System is an allowable variant of the Tone Command System. This system transmits single tones sequentially as AM on a VHF carrier. One of fifteen tones is assigned as a unique spacecraft address and is transmitted first. The execute tones follow to produce a particular command function and may consist of up to 3 tones. The system chosen uses six of the possible seven execute tones in a 3-tone sequence to give 6^3 or 216 commands. Essential commands are redundant in the decoder, reducing the possibility of losing both due to decoder faults.

For command switching, each converter, or separate load, has a latching relay in series with it which is operated according to command pulses fed through a diode steering matrix. The various modes of operation are described below:

Main modes activate the experiments and initiate data transmission or recording in one of the most commonly used experiment configurations (e.g., "All Experiments On"). These main modes require only a single command which is storable for execution at a stored time. This is achieved by a clock and programmer which can store up to five turn-on times in a twenty-four-hour interval and any five of the ten *main-mode* commands. Spacecraft *main modes* are reset to a standard off condition either by a spacecraft manual turn-off or an automatic turn-off.

Spacecraft sub-modes normally provide major modifications to *main modes*. The modifying commands, which set magnetic latching relays as do most of the commands, are reset to the standard *main-mode* condition when the spacecraft is turned off, either directly or by automatic timer.

Equipment sub-modes are used to switch equipment into relatively permanent states of operation (e.g., to engage a redundant unit or to turn off a faulty unit). These commands are not negated by turn-off.

Experimental sub-modes select the internal modes in which a particular experiment will operate. These remain fixed until modified by a further experimental *sub-mode* command.

The command system consists of redundant receivers feeding a command decoder which distributes command pulses to the command switching unit and to other units (Fig. 2). A redundant clock and programmer supplies timing signals and time code to other subsystems and provides remote turn on capability. An automatic turn-off unit (ATO) with internal redundancy prevents accidental discharge of the batteries.

Power System

Power for the spacecraft is generated by an array of 11,130 solar cells arranged to form 174 separate circuits with 62

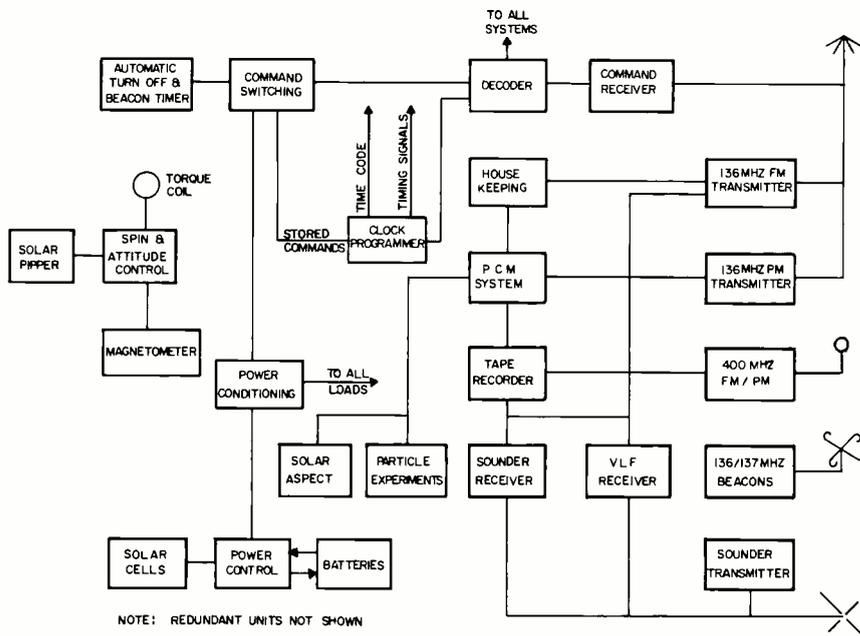


Fig. 2—ISIS A overall system

cells in series. The circuits are mounted on 16 solar cell panels which are placed symmetrically around the spacecraft so that a uniform number of strings are illuminated for all sun orientations. The circuits are combined into three separate charging rails, each capable of producing a 1-amp current early in life. The effects of charged-particle radiation and micrometeoroid erosion are reduced by a 0.030-inch fused-silica cover glass; the current from each charging rail will be 700 mA after one year in space. The N-on-P cells have a resistivity of 10 ohm-centimeter with a blue-shifted spectral response.

There are three batteries of 17 nickel cadmium cells, each having 8.5 ampere-hour capacity; discharge voltage is $+21.5 \pm 2.15$ volts. In normal operation, each battery can withstand continuous overcharge at one ampere. If any battery fails, its loads and charging currents are switched equally to the remaining batteries. The charging current is then controlled by a coulometer which integrates the battery current and signals a fully charged condition at which time the charging current is reduced to a safe level. The minimum expected period of daily operation is still met at the expense of increased depth of discharge.

The power system loads are divided into permanent and switchable categories. Permanent loads such as command receivers, decoder and clock are fed from a common diode rail (CDR) which can be fed by any or all of the batteries or a charge rail. Some switchable loads are switched directly to batteries while others are fed by DC-DC converters of which there are five in the power conditioning system, one for each

of the three telemetry systems and two for the sounder experiment.

These converters reduce interference by operating in the 30-40 kHz range which is above the highest VLF and below the lowest sounder frequency. They provide overload protection and voltage limiting as a protection against failures in the primary power system such as a battery open circuit on charge. Experimental loads connected to batteries are protected by series circuits against over voltage or over current, or in some cases both.

The typical mode of operation requires 90 watts of power which can be delivered for 13 hours per day in early life in full sunlight, and for a minimum of 6 hours per day in minimum sun after 1 year in orbit.

Attitude Sensing and Control

The attitude of the satellite is measured by a solar-aspect sensor and a 3-axis flux-gate magnetometer. The solar-aspect sensor gives an eight-bit reading of the angle between the spin axis and the sun line. This value is read out once per second and is updated at each spacecraft revolution. Magnetometer readings taken once per second are compared to the known magnetic field at the satellite position. These readings and the solar aspect are used to compute the spin-axis direction. The phase of rotation is given by a separate pulse from the solar-aspect sensor when it passes through the plane containing the spin axis and the sun. A schedule of spin and attitude system operation is arrived at by computer reduction of the spin and aspect data, and manual commands are issued to the spacecraft.

Control torque for spin and attitude is provided by passing current through a pair of air-core coils which are wound about a spacecraft meridian to produce an azimuthal magnetic moment. The spin rate, nominally 3 r/min can be increased or decreased by reversing the coil current in the correct phase. The system is capable of about 0.1 r/min change per orbit and is turned off automatically after one hour of operation.

Attitude is controlled by switching the coil current under the control of four solar sensors. These sensors are mounted on the equator and give a pulse each time they pass through the sun spin-axis plane. The system is capable of about 2.5-degree change per orbit at nominal spin rate in 100% sun. Either system is switched off automatically to conserve power if the earth's field is less than one-tenth oersted.

Reliability

The system reliability goals were translated into unit reliability goals by apportionment in ratio to the number of components in each unit. Generic failure rates for the components were used to establish relative failure rates, thereby setting a realistic goal for each unit. (A unit is defined as an engineering module or subdivision uniquely concerned with a particular combination of experiments.) Grouping all units affecting the same combination of experiments permits the construction of a reliability flow diagram; the flow diagram for the final system is shown in Fig. 3, where housekeeping is treated as another experiment with a subdivision for essential housekeeping. Fig. 3 is simplified in that it does not show those relationships having a negligible effect on reliability, and some of the equipment groupings are rather coarse. With this diagram it is convenient to assess the relative criticalness of the groups and determine system failure propagation.

Neglecting the redundancy indicated in Fig. 3, it is obvious that all equipment at the top of the diagram affects all experiments, and in addition their failure rates are relatively significant. Therefore redundancy is introduced to improve overall reliability and reduce the probability of a first failure effect. Thus, the command receiver, clock and programmer, and ATO unit have redundant units. The back-up clock and programmer, which can be made operational by command, is a simpler unit than the original with less flexibility and fewer programming stores. Although not shown in the simplified diagram, most of the critical units have considerable redundancy. For example the power system requires only

two out of three batteries, and the Command Decoder has redundant codes for essential commands with additional safety in the command flexibility. Loss of spin and attitude control would not jeopardize all experiments provided that attitude data were available. Loss of the 400-MHz transmitter would still leave all data available in the direct transmission mode; the 400-MHz transmitter can act as an alternate path for real-time data transmission, but this is not shown in Fig. 3.

Further down the flow diagram, the PCM encoder affects six experiments, and a single failure will probably jeopardize more than three of them. Thus, a passive redundant encoder is included. The mode power switches tended to contribute a significant failure rate, so redundant active contacts were used. The remaining groups with relatively large failure rates are in the sounder system, but it is impractical to use redundancy because there is no unit that has a significantly large failure rate; the

complexity is inherent in the experiment and little can be done for improvement. Redundant transmitters are included at the customer's request and reduce the probability of a first failure effect. The remaining equipment affecting only one experiment has no redundancy.

Even after the preceding improvements, the clock and programmer still has the largest failure rate, since it contains over one-third of the total number of components (solar cells excepted); however, further increases in reliability are impractical. Loss of the clock and programmer would mean loss of remote operation and considerable inconvenience in the direct transmission mode; however, experimental data would still be available.

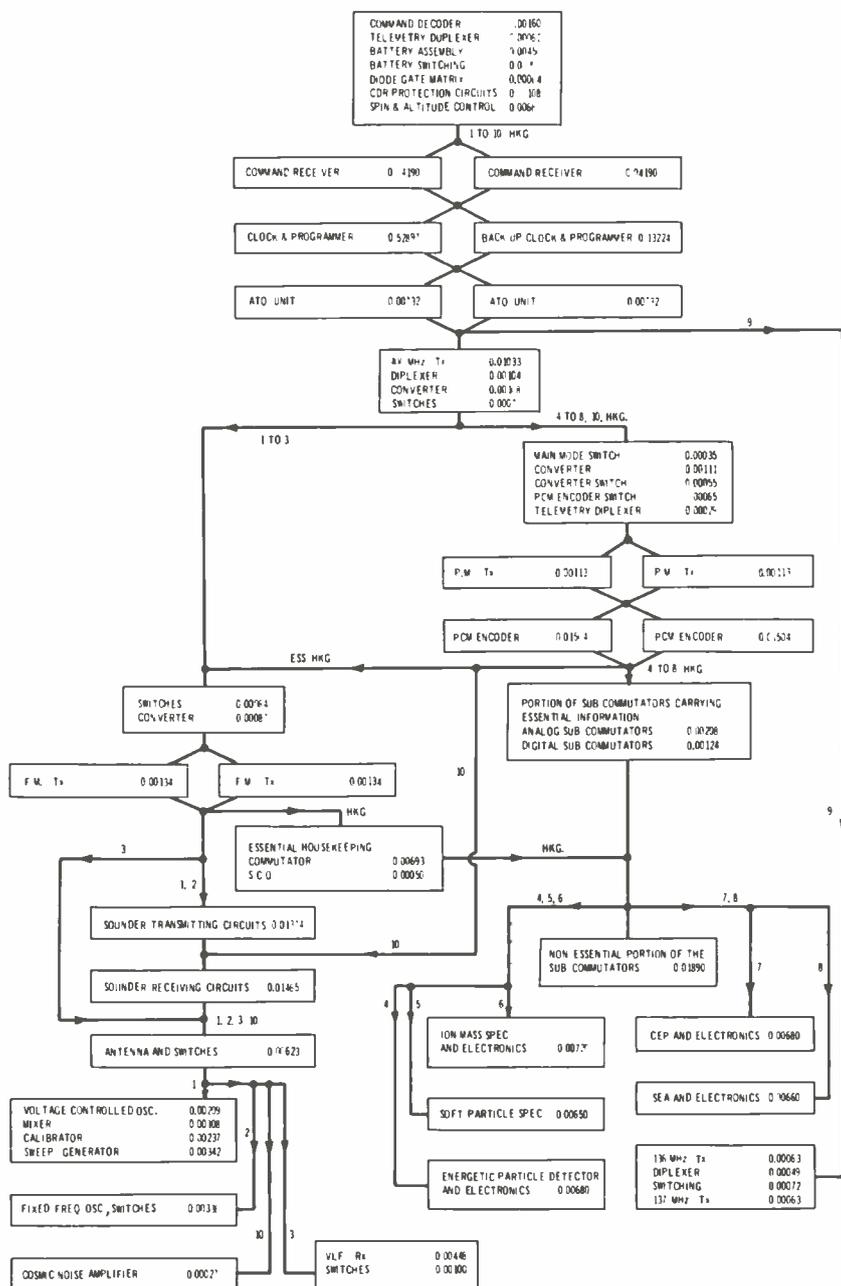
Failures will occur, however, so it is important to design such that failures cause minimum possible data loss. For example, the command decoder can affect all experiments, but a single gate failure affects only a localized area of circuitry. Therefore the command allocations should be such as to place commands affecting a single experiment in this localized area so that a failure affects only one experiment (with the exception of redundant commands). A similar approach was used in the design of the commutating circuits. Alternatively when such a separation cannot occur, the design should be such that a failure will only reduce flexibility rather than cause complete data loss.

With the preceding improvements, and the redundancy as indicated in Fig. 3, the calculated probability of completely satisfactory operation at the end of one year in orbit is 0.813, and the probability that a first failure would affect more than three experiments is 0.041. These figures show that the Isis "A" system meets the reliability goals, provided that the units meet their individual reliability goals. Even if the tape recorder were included in the reliability calculations, the probability of completely satisfactory operation is still 0.79. When a mission success is defined to require experimental data in the direct transmission mode only, then the clock and programmer and associated remote operation equipment do not enter reliability calculations. The probability of a mission success at the end of one year in orbit is then 0.89 with a 60% confidence level.

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Fig. 3—Simplified reliability flow diagram for the Isis A spacecraft showing failure rates per operating year.



COMMAND, TELEMETRY, AND TRACKING SYSTEM FOR THE ISIS A SPACECRAFT

The ISIS A satellite telemetry, command, and tracking systems are described in some detail as are the antennae and units making up the systems. The telemetry system includes two 136-MHz real-time data links, one FM for sounder video transmission, and one PM for PCM transmission. A 400-MHz link of increased bandwidth is used to playback tape recorded data at four times the record speed and to act as a real time back-up for the 136-MHz system. Commands corresponding to main modes of operation of the satellite are stored, along with stored times, in a content-addressed magnetic memory in the clock and programmer. The antenna system includes a four-element VHF turnstile fed by a low-loss diplexer and duplexer featuring strip-line couplers and an annular slot 400-MHz radiator. The extendible sounder antennae are briefly described.

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Systems Design, Digital and Analog Equipment Design, and Antenna Design

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THE ISIS A ionospheric sounding satellite is now under construction at RCA Victor. The principal experiment aboard this satellite is the ionospheric sounding which is performed by a pulsed swept-frequency signal. The frequency coverage is from 0.1 MHz to 20 MHz. The swept frequency system is supplemented by a fixed frequency sounder operating at six selected frequencies between 0.25 and 9.3 MHz. A unique feature of ISIS A is the antennae associated with the sounder experiment.

TELEMETRY AND TRACKING SYSTEM

The telemetry and tracking system (Fig. 1) consists of two main subsystems: one for use in direct real-time transmission and the other for transmission of tape recorded data with a speed-up playback (4:1). The first subsystem operates in the 136-MHz telemetry band,² and the second operates in the 400-MHz band.

The 136-MHz portion consists of two redundant pairs of transmitters: one pair of FM transmitters with a 100-kHz transmission bandwidth and one pair of PM transmitters with a 50-kHz transmission bandwidth. Either FM transmitter is selectable on command and is modulated by a sounder video waveform which is an analog signal (dc to 15 kHz) consisting of synchronizing and calibrating pulses at 30 or 60 pulses/second plus echo returns. It may be modulated also by the output of a VLF receiver in the 50-Hz to 30-kHz band, either on a time-shared

basis with the sounder or combined with the sounder. The carrier is continuously modulated by a 30-kHz IRIG FM subcarrier³ which is normally modulated by the output of a 30-channel essential house-keeping commutator. The commutator output is replaced by clock and programmer data (60 pulse/second BCD code) for five seconds at the beginning of each minute. The FM transmitter output is fed to a diplexer which feeds a four-element turnstile antenna.

Data from all experiments other than the sounder and VLF are time multiplexed and encoded using one of a redundant pair of PCM encoders⁴. The output of the encoder in split-phase format is used to phase modulate one of the PM transmitters. The transmitter output is duplexed with the command receivers and feeds the same duplexer and turnstile antenna as the FM transmitter. All designs must meet specifications over a temperature range of -5 to $+40^{\circ}\text{C}$ and must operate over the range -50 to $+75^{\circ}\text{C}$.⁵

136-MHz FM Transmitter

The 136 MHz FM transmitter is a four-watt unit with a basic design that has proven successful on ALOUETTE I and II. It consists of a 17-MHz crystal oscillator employing crystal pulling for frequency modulation. This method requires careful control of spurious modes of crystal oscillation to control stability and modulation distortion. The oscillator is followed by three stages of buffering, and doubling by varactor multipliers. The final amplifier is a single 2N3375

transistor feeding the output via a band-pass filter which is necessary to meet the NASA spurious emission requirements.² The design employs conventional discrete components and the construction is by a series of individual compartments milled from an aluminum block.

136-MHz PM Transmitter

The 136-MHz PM transmitter is a two-watt unit consisting of a 34-MHz crystal oscillator with two stages of buffering and varactor doubling, followed by a final amplifier and filter. The phase modulator is a two-varactor high-pass low-pass interstage filter design. In this arrangement, the incidental amplitude modulations are complementary and so tend to cancel, while the phase modulations add and some of the modulation non-linearities cancel. The design of the transmitters is similar to that of the FM units.

PCM Encoder

The PCM encoder employs a frame of 24 words of 8 bits each (192 bits), with 60 frames per second (11,520 bits/sec).⁴ Some data are in the form of slowly varying voltages in the range 0 to +5 volts with frequency components not over 25 or 50 Hz. These are sampled once or twice per frame, according to the bandwidth required, by a commutator consisting of analog gates connected to a common output. These gates use field effect transistors (FET) as analog switches, and are opened in a sequence defined by a counter using integrated logic circuits. The samples are held by a sample and hold circuit and then encoded by an A/D converter of the cascaded feedback type. The encoder output is stored in a shift register and clocked out at the appropriate time with the most significant bit appearing first in the output. Some data, which are already in the form of bits stored in experiment shift registers, are fed word sync pulses at the appropriate time and bit sync which is then used to clock out the contents of the shift registers. During these intervals, the commutator and A/D converter are inactive.

Two words are available as 16 parallel access bits for a digital flag sub-commutator and various high speed flags such as a solar aspect sensor and a 60 pulse/second BCD time code. Two analog words are used to carry the output of two 60-channel analog sub-commutators. Frame sync consists of the first sixteen bits in a pseudo-random pattern. Inputs to the redundant encoders are normally fed by separately buffered outputs but in some cases may be connected in parallel. The encoder design attempts to minimize the probability of loading parallel inputs under

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failure conditions. The inactive encoder as well as all inactive units using FET's as series switches are maintained in the pinched-off condition by a permanent "keep alive" voltage. The design uses discrete components and integrated circuits on single-side printed circuit boards mounted in sandwich style.

Analog Subcommutator

Each analog subcommutator scans 60 channels/second, giving an individual channel sampling rate of one/second. The commutators are not redundant because the experimental data on either subcommutator are not carried by both units nor by other means. Thus, the commutators are designed as five-layer trees to reduce the possibility of catastrophic failure. A combination of relatively low source resistance for experimental outputs (~ 10K) and a high input resistance (1 Meg) in the PCM encoder ensures that the 1% PCM accuracy aim is not compromised by the series elements. Fifteen channels on each commutator arranged in 5 groups of 3 are available as low-level inputs (100 mV full scale). These channels are amplified by a single differential amplifier after commutation. This method minimizes the number of amplifiers used, at the expense of lower accuracy in these channels due to amplifier input leakage current flowing through series FET switches. Subcommutator synchronization is achieved by resetting the counters to the "channel one" condition with a separate divide-by-60 counter which also provides subcommutator sync indication as a "true" condition on the first three bits of the sixteen parallel-access PCM bits. The design uses both discrete and integrated circuits and construction is by single-side printed-circuit mother boards mounting "flat pack" logic integrated circuits and "cordwood module" discrete components.

Digital Subcommutator

The digital subcommutator is a 60-input unit using gated counters scanning a 5x12 matrix. It is driven and synchronized in the same way as the analog subcommutators to give a channel information rate of one bit/second. Inputs are compatible with flat-pack logic (0 and +5 volts) or with relay contact closures (short or open) and are designed for greatest noise immunity.

Tape Recorder

The tape recorder is a four-track unit in a pressurized container which records sounder video, VLF, PCM and time code on separate tracks. The sounder video modulates the period of an oscillator in the recorder whose output gives



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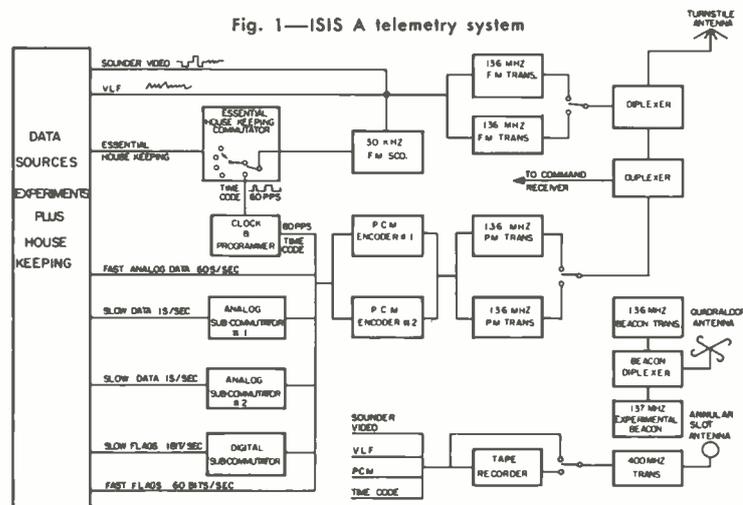
JOSEPH ZURAN received the Dipl.ING. degree in mechanical engineering from the University of Belgrade in 1941 and the M.Sc. degree in electrical engineering from the University of Ljubljana in 1949. During World War II, he served with the RAF in the Middle East. From 1946 to 1949, he was Assistant Lecturer at the Faculty of Electrical Engineering, University of Ljubljana. From 1949, he was chief of transmitter group of the Institute of Telecommunications, Ljubljana, and in December 1954 joined the Marconi Wireless Telegraph Co., Chelmsford, England, working on advanced high power transmitter designs. From 1958, he was in charge of the Antenna Development Section at the Marconi Research Laboratories, Gr. Baddow, Essex. He joined RCA Victor Company, Ltd., Montreal, Canada as specialist engineer in 1960. Since then he has been responsible for the development of RCA Victor log-periodic antennas, wideband high power transformers, and multi-channel TV antennae for Canadian Broadcasting Corporation and is presently with Aerospace Engineering, responsible for spacecraft antenna systems and design. He holds several patents on high power transmitters, helical resonators and wideband antennas. Mr. Zuran is a member of the IEE (Great Britain), the IEEE (US) and a member of the Corporation of Professional Engineers, Quebec, Canada. He is also a member of Professional Groups on Antennas and Propagation and Microwave Theory and Techniques.

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of telecommunication problems including airborne VHF transceivers, UHF troposcatter telephony, and heavy route microwave telephony. He was engaged in design and system integration of the NASA RELAY communications transponder and recently participated in communications satellite proposals to COMSAT Corporation. He is a member of the Quebec Corporation of Professional Engineers, the Engineering Institute of Canada and the IEEE. He is currently Spacecraft Systems Engineer for the ISIS A Program.

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Fig. 1—ISIS A telemetry system



saturation recording on one track; VLF signals are recorded on a normal AC-biased track. PCM signals are provided in NRZ-C format but are converted by the recorder before recording, to a split phase format. Time code in a 60 pulses/second BCD pulse-width format is used to amplitude modulate a reference PCM bit rate signal which is recorded on the fourth track. The tape recorder is controlled remotely by commands stored in the clock and programmer and may record for several periods for a total of 65 minutes. The normal record period is 16 minutes at 5 in/sec and the playback is in reverse order at four times this speed. A period discriminator restores the sounder video waveform and the split phase recorded PCM data is restored to NRZ-C format. VLF and time code are available without special processing in the tape recorder. The outputs are played back over the 400-MHz link.

400-MHz Transmitter

The 400-MHz transmitter is a four-watt unit with both FM and PM modulation capability and contains a latching relay switching unit for input signal switching of played-back data or real-time data. The RF portion of the transmitter consists of a 17-MHz crystal oscillator, capable of frequency modulation by crystal pulling, feeding a buffer and varactor quadrupler. For this application, the crystal must be free of spurious resonant modes over an unusually large band because of the modulation frequencies involved which can be up to 80 kHz. This stage feeds a buffer and tripler circuit via a single tuned phase modulator interstage network. A further buffer and doubler circuit provides 2 watts of power at the output frequency which is then used to drive the final amplifier to the required four-watt output level.

A final filter is required to keep crystal harmonics from exceeding the speci-

fied output level. The power output is fed directly to an annular slot antenna mounted on one end of the spacecraft. As well as providing input signal switching, the transmitter also contains a non-standard 93-kHz s.c.o. which may be modulated by various played-back or real-time data. The s.c.o. and the played-back time code which appears as a 240 pulse/second modulation on a 46.080 Hz carrier produce phase modulation of the 400-MHz carrier while the sounder and VLF frequencies modulate the carrier. The transmitter construction is nearly identical to that of the 136-MHz FM and PM units.

Experimental and Tracking Beacons

These units which are identical except for their frequency, radiate 100 mW of unmodulated power and together provide stable frequencies at about 136 and 137 MHz. Their outputs are diplexed together and radiate through four equatorially mounted quadrupole elements. One frequency satisfies the requirements for a tracking beacon compatible with NASA STADAN² facilities while the two together are used to study ionospheric irregularities.

The beacon design consists of a seventh-overtone crystal oscillator operating at the output frequency, followed by a buffer and final amplifier. Particular care is taken in the design to minimize the effects of temperature and voltage fluctuation on frequency. Low power dissipation in the crystal also minimizes long term aging effects. Worst case combination of voltage fluctuation and temperature shock still result in stabilities better than 10^{-6} without the use of crystal ovens. Tests at atmospheric conditions have shown that the difference frequency between beacons may vary as little as 10^{-7} for periods of 10 minutes during thermal transients. This is probably because of nearly identical construction and frequency-temperature characteristics.

COMMAND SYSTEM

The command system accepts approximately 150 commands via radio link from ground stations, decodes these commands into control signals for spacecraft equipment either immediately on reception or after a command delay, and ensures that spacecraft equipment is turned off after a suitable operating period in the event of no reception of a deliberate turn-off command.

Reliability and system design of the spacecraft system and experiments dictate different reliability requirements for different commands and functions of the command system. The command switching design separates the commands into four categories: *main modes*, *spacecraft submodes*, *equipment submodes* and *single commands*.¹

The command link to the spacecraft consists of an amplitude modulated VHF carrier, which carries a 7-ary series of tones to the spacecraft in groups of four tones. The first tone is an address tone, and the next three represent one of 216 6-ary characters.

The commands decoded by the command decoder affect operating spacecraft units directly. However, the clock and programmer is an alternative source for some commands (main modes). The clock and programmer is a simple computer with a content-organized memory of ten words. Each memory word can contain a number from one to ten (ten main modes) and a time of day. The memory contents are continually being scanned and compared to a clock; when the clock time agrees with the time stored in a memory location, the associated stored main mode command is executed. The memory of the clock and programmer is filled by simple commands designated for this purpose.

As the capacity of the spacecraft equipment to dissipate power exceeds the capacity of the solar cells, the main

Fig. 2—Command system

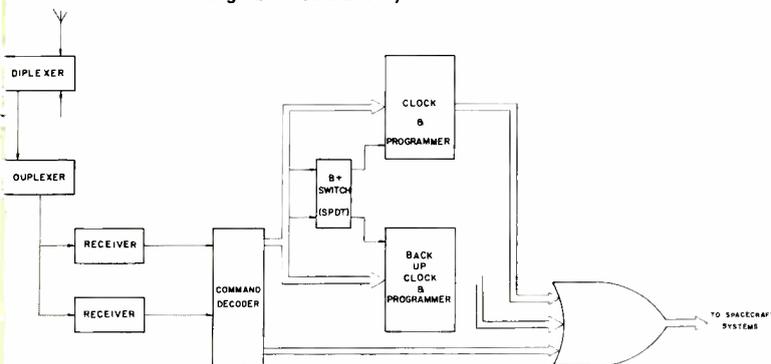
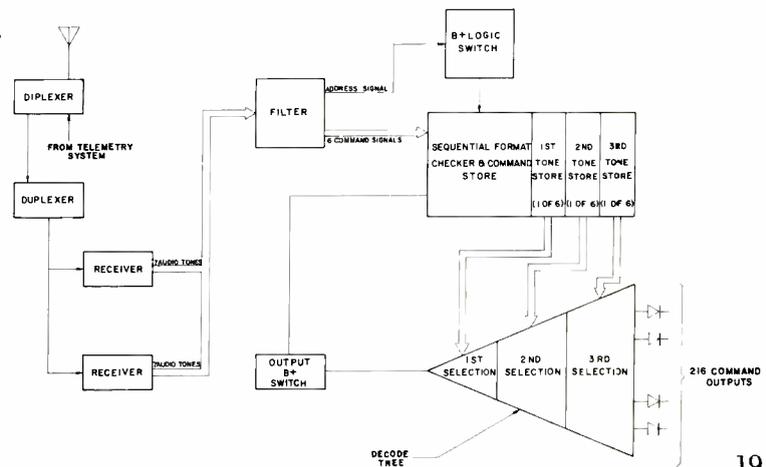


Fig. 3—Command decoder



power drain of the spacecraft is called upon intermittently and is drawn from storage batteries. This arrangement requires that the storage batteries be never fully discharged; the automatic turn-off unit is designed to guarantee this condition. When certain spacecraft functions are turned on by command, the automatic turn-off unit is turned on also, and (after a suitable interval) causes the appropriate spacecraft function to turn off. Thus power consumption is limited in the event of failure to receive a transmitted turn-off command. Fig. 2 is a block diagram showing the interconnection of the units in the command system.

The command receiver decoder combination is redundant providing two receiver decoder pairs, each handling 108 different command codes. Those commands requiring redundancy for enhanced reliability are made up of outputs associated with two command codes, one from each receiver decoder pair, combined in a diode "or" circuit.

Some of the decoded commands, redundant and single, go to the clock and programmer, and some to the other spacecraft units. Delayed mode selections originating in the clock and programmer provide alternates for ten of the forementioned commands.

Command Decoder

Each section of the command decoder (Fig. 3) includes equipment performing the following functions: filtering, format checking, memory, and decoding. The detected signal from the command receiver is presented to seven filters, where the tone is classified as "address" or some "number" one through six. If the tone is an "address", power is applied to the decoder logic; "number" tones following the address tones are stored as decoded lists in flip-flop registers. Upon reception of the third "number" tone, if the message has consisted of one address

and three numbers, and if the durations and spacings of the tones have complied with the required format, voltage is applied to the top of a three-layer tree of transistor switches, 3 in the top layer, 6 in the next, and 108 in the bottom layer. The appropriate switches are held open by the contents of the flip-flop memory, resulting in a current flow from one of the 108 outputs corresponding to the command code received.

Clock and Programmer

The clock and programmer (Fig. 4) consists of an accurate clock, a program store, command inputs, command outputs, serial data outputs, timing pulse outputs, and control logic. The clock is an accurate (0.5 part in 10^7) temperature compensated crystal oscillator, whose output is divided down by a counter to provide a time code. The program store is a content-addressed magnetic memory of ten words, each word capable of storing a time of day and one of ten characters corresponding to the ten main modes. The contents of the program store is defined by a series of commands from the command decoder.

The time of day portions of the program store words are being continually compared to the time code, and when agreement is observed, the associated mode command is issued, and the time portion of the word is replaced by an inadmissible time (29:00 hours).

The clock and programmer is paralleled by the back up clock for reliability. These two units receive power via a type-C magnetic latching relay.

Automatic Turn-Off Unit

The automatic turn-off unit is essentially a redundant pair of clocks timing the turn-off of the spacecraft equipment. The main unit consists of a magnetic shift register, counting minute pulses provided by the clock and programmer. This counter is turned on automatically, and times for sixteen minutes. By command, this time can be changed to eight or twenty-four minutes. The main unit is paralleled by the back-up automatic turn off unit, which consists of an oscillator and thirty-minute magnetic counter.

RADIATING SYSTEM

The antenna complement of Isis A is a set of crossed dipoles, 61.5 feet and 240 feet long for ionospheric sounding, a VHF broadband turnstile array for telemetry and command, a telemetry UHF annular slot antenna, and a quadraloop antenna array for the beacon and beacon experiments. The locations and orientations of these antenna elements provide optimum radiation

patterns at minimum mutual coupling.

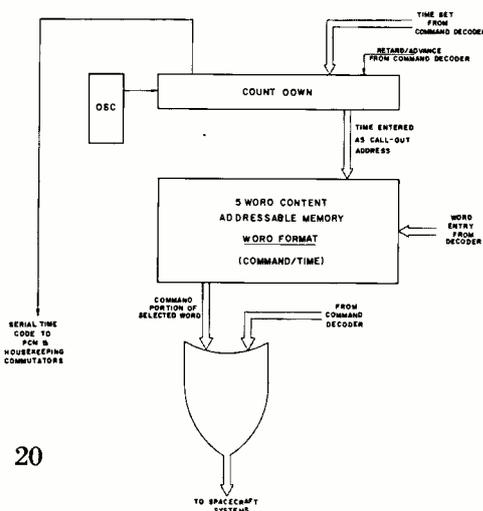
The VHF telemetry and command systems share the same antenna. In orbit, the attitude of the spin-stabilized spacecraft continuously changes with respect to earth and a nearly isotropic radiator is required for continuous telemetry and command operations. A broadband circularly polarized monopole array in turnstile configuration provides the best solution at VHF frequencies. The array is located around the end of the spacecraft thrust tube which is attached to the launching rocket by a marman clamp. The sleeve-type monopole elements of the turnstile array have a broadband characteristic with 30% frequency bandwidth and have a nominal input impedance of 50 ohms. The PM and FM transmission use opposite rotations of polarization controlled by the phasing characteristic of the telemetry diplexer. The design of the telemetry antenna system is governed by bandwidth requirements; isolation requirements between transmitters and receivers; attenuation of harmonics; and high isolation between transmitters to prevent cross modulation between the two transmitters.

The heart of the telemetry antenna system is the S-type diplexer which combines a broadband characteristic with a low insertion loss, low VSWR, and high isolation between transmitter input ports. The S-diplexer, which is a 3-dB strip-line coupler using Faraday screening, offers particular advantages over the conventional coaxial hybrid when antenna arrays are to be connected in phase quadrature over wide frequency bands. The diplexer provides an isolation in excess of 45 dB between telemetry transmitters at an insertion loss below 0.2 dB. The VSWR at the input terminals of the diplexer is less than 1.05. The power ratio at the two antenna ports is within ± 0.25 dB. The deviation from phase quadrature at transmitter and receiver frequencies is within ± 2 degrees.

The main and standby FM and PM transmitters are connected to the switching unit, which is operated on command. A system of SPDT latching relays connects the selected FM transmitter to the diplexer and feeds the selected PM transmitter into the diplexer. The switching unit is combined with the telemetry/command diplexer.

The telemetry/command diplexer isolates the transmitters from receivers by 50 dB and provides an additional 50-dB attenuation of 2nd harmonics in the path of the PM transmitters. The output port of the diplexer is connected to the common transmitter/receiver terminal of the telemetry/com-

Fig. 4—Clock and programmer



mand diplexer. In the command antenna system, the RF signal which is intercepted by the turnstile antenna is fed into the diplexer and picked-up at the common transmitter/receiver terminal of the diplexer. From this terminal, the receiver signal is fed into the duplexer which provides a 3-dB power split with an isolation of 40 dB. The two command receivers which are connected to the duplexer feed the command decoder.

The duplexer is designed as a combination of a folded comb-line filter and an S-type 3-dB strip-line coupler using the same basic design as the telemetry/command diplexer. The height of the resonators of the comb-line bandpass filter is less than one-sixteenth of a wavelength at 136 MHz, thus resulting in a compact lightweight unit.

The broadband metallic matching sleeves of the turnstile monopole elements are attached to base-mounts by threaded fittings enabling the antennas to survive the high vibration levels at launch. The nominal input impedance (50 ohms) of the monopoles permits connection of dummy loads at the base of antenna mounts for rapid check-out of the telemetry system prior to launch.

The broadband diplexer provides high stability of operation at wide temperature variations from -50°C to $+70^{\circ}\text{C}$. Due to the inherent phase quadrature at the ports of the diplexer, the RF harnesses feeding each pair of monopoles are identical. As a result, a small number of soldered cable junctions is used, reducing the harness insertion loss and increasing the reliability of operation of the system.

The 400-MHz telemetry antenna system utilizes an annular slot antenna with a back-up cavity. A broadband radial transmission line transformer, forms an integral part of the cavity and matches the antenna to the transmitter over a wide frequency band. The antenna system is trimmed for minimum reflection (1%) at the transmitter frequency using a shorted coaxial stub.

The annular slot antenna is designed to operate as an electrically short radiator near the lower cut-off frequency with surface currents flowing across the near-spherical spacecraft body of one wavelength diameter. The combined effect is a good omnidirectional, linearly polarized, radiation pattern. The broad doughnut pattern has two nulls in both directions of the spin axis.

The supporting booms for the Langmuir and ion probes are mounted close to the annular slot antenna and are decoupled from the antenna surface currents by a system of ferrite chokes mounted along both booms. The effect of the metallic booms on the antenna

radiation pattern is thus reduced.

The antenna surfaces are highly polished and form a part of the heatshield of the spacecraft. For the same reason, the antenna back-up cavity is embedded in a thermo-insulated container.

The beacon radiating system has manifold functions. The antenna array radiates a 136-MHz CW signal for tracking purposes in conjunction with a 137-MHz beacon for the study of ionosphere irregularities and electron content of the ionosphere.

The University of Western Ontario is the principal user of the beacon facility for studying isolated ionospheric irregularities. Small-scale variation in the total electron content of the ionosphere are studied using the differential polarization method (measuring the instantaneous difference angle between polarization received at the two beacon frequencies).

The closely spaced frequency method is used to determine the total electron content of the ionosphere averaged over several degrees of orbit path. Simultaneous amplitude and phase scintillation measurements of the received signal provide information for establishing the ionic inhomogeneities responsible for these scintillations.

Depending on the experiments, either circular or linear polarization is used. The antenna provided for these experiments is an array of four loop antennas mounted on the equatorial panels between the sounder antenna monopoles. The antennas are fed in phase quadrature, providing a circularly polarized pattern in the direction of the spin-axis of the spacecraft and mainly linear polarization in the direction perpendicular to the spin axis. The quadrature antennas are shorted quarter-wave transmission-line radiators, capacitively loaded at the open ends by slug-type capacitors.

The individual quadrature loops have a nominal input impedance of 50 ohms and are fed by a coaxial-cable phasing network. The common cable junction has an input impedance of 12.5 ohms. The transformation to 50 ohms is achieved by two quarter-wavelength 50-ohm cable sections in parallel. Thus, the same cable is used throughout.

The beacon antenna system features a novel type of strip-line diplexer, combining the two transmitters operating at closely spaced frequencies into a common 50-ohm antenna terminal. The diplexer consists of a half wavelength 3-dB coupler with Faraday shielding posts, assisted by two helical resonators. With matched output terminals, the diplexer provides isolation between transmitters in excess of 45 dB at 1% frequency separation over a temperature range from -50°C to $+70^{\circ}\text{C}$.

The insertion losses are 0.9 dB and 0.7 dB between the output and the two input ports of the diplexer. The VSWR at input ports does not exceed 1.1:1.

The sounder antenna system is essentially the same as those for ALOUETTE I and ALOUETTE II. The sounder array has a crossed dipole configuration mounted in the equatorial plane of the spacecraft. The dipole radiation pattern is derived from two pairs of monopoles, each pair driven in antiphase by a quasi-coaxial feed system. The pairs operate sequentially in two bands over the frequency range of 0.1 MHz to 20 MHz, with a crossover frequency at 5 MHz. The length of the shorter dipole and the crossover frequency are determined by the pattern requirements allowing a maximum side-lobe level of 10 dB below the main lobe and also to ensure antenna efficiency at the lower end of the high frequency band. The antenna elements are made of preformed tubular beryllium copper tape, and stored in the antenna module before and during launch. The antenna elements are individually extendible in orbit by means of an electric motor mechanism activated on separation from the launching vehicle or on command.

The antenna modules are equipped with speed control circuits which maintain correct de-spin rate of the spacecraft during deployment of antenna elements. The modules are double shielded coaxial units with RF shielding in excess of 100 dB.

The four modules are radially mounted on the thrust tube of the spacecraft and fed via a combining crossover network mounted inside the thrust tube. The crossover network consists of a low-pass high-pass filter and a TR switch. In orbit, the long sounder antennas cut the lines of earth's magnetic field and build up a potential proportional to $\mathbf{V} \times \mathbf{B} \cdot \mathbf{L}$, where \mathbf{V} is the spacecraft velocity, \mathbf{B} is the earth's magnetic field and L the length of antennas. To free the spacecraft from the ion sheath generated by the $\mathbf{V} \times \mathbf{B} \cdot \mathbf{L}$ effect, all four antenna modules are equipped with ion guards in the form of cylindrical 3-foot-long silicone rubber sleeves mounted at the root of each antenna element. In addition, the antennas are coupled capacitively to the crossover network to prevent DC from reaching the spacecraft.

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THERMAL DESIGN OF THE ISIS A SPACECRAFT

The thermal design of the ISIS A spacecraft was dictated by details of the structure, orbit mission, on-board temperature limits, and payload power dissipation. Consideration of these factors showed that 'passive' thermal control of the spacecraft was feasible. A computer programmed multi-node heat balance analysis is described which has been developed and used to predict spacecraft flight temperatures and evaluate design parameters. The scope of a thermal-vacuum test program required to establish design integrity is outlined.

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ALL the experiments and electrical systems are on the Isis A spacecraft thrust tube and equatorial panels. (A complete description of the spacecraft is given in Reference 1). Because Isis A will be spin stabilized (with a design spin rate of 3 r/min) net heat inputs will tend to be axially symmetric for any sun-spin vector orientation. As the spin stabilization does not prevent long-term large-amplitude spin-axis excursions all sun-spin vector orientations must be considered. Thus sixteen sloping trapezoidal solar cell panels were used to provide fairly constant solar cell aspect ratio for the complete range of sun-spin vector orientations, without allowing the absolute minimum aspect ratio to fall significantly below the mean. (The solar cell aspect ratio is the projected solar cell

area in any direction divided by the total solar cell area of the spacecraft.) Solar aspect ratio of a sphere is 0.25; values for Isis A range between 0.215 and 0.260.

The estimated electrical power dissipation for the electrical systems is 60 watts continuous over an entire orbit. Depending upon the mode of equipment operation, the instantaneous dissipation range can be from 120 watts to nearly zero. The required flexibility is provided by 51 nickel-cadmium storage cells grouped into three 17-cell batteries; these can supply power, in addition to the conversion rate at peak demand and low solar input, and store energy during low demand and high solar input.

The temperature constraints of various components of the spacecraft, including the storage batteries, are -5°C to $+40^{\circ}\text{C}$. These limits must prevail for all satellite orbit and attitude configurations. This includes the launch phase during which time the spacecraft will not be spinning and for which a special ascent heating calculation must be performed.

THERMAL CONSIDERATIONS

The thermal design techniques used for ALOUETTES I and II were developed further for Isis A.

The average surface properties of the spacecraft are based on the maximum and minimum heat inputs averaged over an orbit. The inputs come from the sun, the earth, and from spacecraft internal heat dissipation (Fig. 1).

There are two heat inputs from the earth: infrared radiation due to the earth's internal temperature, and reflected radiation from the sun (albedo). The earth infrared input to the spacecraft is a function of altitude, while the solar reflected radiation is a function of both altitude and the angle between the earth-sun and earth-spacecraft vectors. For the nominal Isis A orbit, the average infrared input is about 10% of the solar input, and the reflected solar radiation can vary from a maximum average over

one orbit of about 10% of the solar input to zero, depending on the angle between the sun-earth vector and the orbit plane. The maximum instantaneous value of reflected solar radiation is almost 50% of the direct solar input. The extreme conditions possible are listed in Table 1.

In addition to variations in heat flux, there is the possibility of variations in spacecraft-sun aspect. Due to gravitation forces, the orientation of the spacecraft spin axis can change through a large amplitude for periods of several weeks. Thus, the surface of the spacecraft must be designed so that the heat intake is, as near as possible, independent of the spin-axis orientation.

For Isis A, the solar cells are on panels which are part of the external shell. The distribution of solar cells on the surface is dictated by the necessity for having a constant rate of conversion of solar power, independent of the spin-axis orientation.³ Fortunately, this tends to agree with the thermal need for a constant $(\alpha/\epsilon) \times \text{Area}$, independent of orientation.

In the direction normal to the spin axis, the average heat intakes are:

$$\text{Direct solar radiation} = A_H \bar{\alpha}_H SP \quad (1)$$

$$\text{Earth reflected radiation} = A_H \bar{\alpha}_H R \quad (2)$$

$$\text{Earth infrared radiation} = A_H \bar{\epsilon}_H E \quad (3)$$

$$\text{Payload power dissipation} = P' \quad (4)$$

The heat loss is

$$A \bar{\epsilon} \sigma T^4 \quad (5)$$

Thus, the heat balance is

$$A \bar{\epsilon} \sigma T^4 = A_H \bar{\alpha}_H (SP + R) + A_H \bar{\epsilon}_H E + P' \quad (6)$$

In general, similar equations can be written for any orientation of spin axis. Therefore, the spacecraft mean temperature is a function of α/ϵ for the various external surfaces, and, to some extent, is a function of $|\bar{\epsilon}|$.

Thus, temperature of an earth satellite is affected by surface configuration, radi-

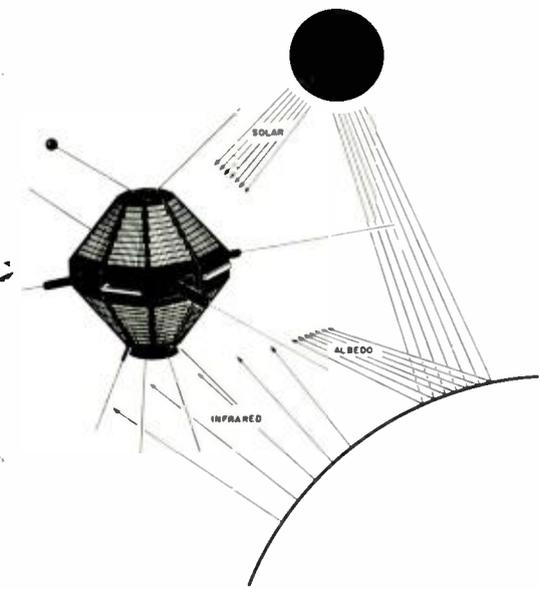
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LIST OF SYMBOLS	
A	Surface area
A_H	Horizontal projected area
E	Earth infrared heat flux
F_{ij}	Black body radiation shape factor from node i to node j
M	Thermal mass
P	Percent sun
P'	Payload power dissipation
R	Earth reflected solar radiation
S	Heat flux from sun
T	Absolute temperature
t	Time
α	Solar absorptivity
β	Solar aspect ratio
k_{ij}	Conductance from i to j
η'	Node solar radiation conversion efficiency
ϵ	Infrared emissivity
\bar{G}	$\frac{1}{A} \int_A \frac{\exp(-\eta^2)}{2s\sqrt{\pi}} dA$
\bar{F}	$\frac{1}{A} \int_A \frac{\eta(1 - e\gamma f\eta)}{2s} dA$
C	Accommodation coefficient
N	Number of molecules/unit volume
σ	Stefan Boltzmann's Constant
T_o	Free stream temperature
u	Mass velocity
\bar{Q}	Average heat transfer/unit area
γ'	Ratio of specific heats
T_w	Temperature of wall
s	Ratio of most likely molecule speed to spacecraft speed
η	$S \sin \theta$
θ	Angle of incidence
γ	Earth aspect ratio
	Average values denoted by a bar.

Fig. 1—Radiation inputs to spacecraft.



RADIATION ARRIVING AT SPACECRAFT

	SOLAR BTU/HR	REFLECTED SOLAR BTU/HR	EARTH INFRARED BTU/HR	PAYLOAD HEAT BTU/HR
100% SUN	5050	350	590	340
67% SUN	3330	360	590	0

Table 1—Heat inputs to spacecraft.

ative properties of the surface, internal heat dissipation, spacecraft orientation, and orbit parameters.⁴

The heat dissipation term in the heat balance equation is smaller than the other terms but is significant in establishing the radiation coupling required between the spacecraft interior and the surface. For Isis A, high emissivity surfaces were required.

Passive thermal control is used in the Isis A spacecraft. A passive design is one in which the selection of surface radiation characteristics is such that the spacecraft will operate within an acceptable range of temperature limits. The alternative, active control, implies the use of devices which will function in space to control a heater, cooler, spacecraft attitude, radiation characteristics of surfaces, or any combination of the above. Passive control is inherently simple and the reliability problem associated with actuated components is not present; however, no measures can be taken to compensate for changes in surface properties with time and variations in spacecraft attitude or orbit parameters. In

this connection it is virtually impossible to effect a totally passive design for space missions where the distance from the sun to the spacecraft will vary appreciably during the mission. With active control, it is possible to compensate for variations in the factors mentioned above. Most earth-orbiting scientific satellites have passive temperature control designs, whereas deep space probes have semi-active or fully active designs and manned spacecraft have complex active control.

CALCULATIONS

Orbital Temperatures

The thermal design based on average absorptivity, emissivity, areas and heat fluxes produced a temperature range of +2°C to +35°C. As the desired temperature range is -5°C to +40°C, there is a little in reserve, so knowledge of variations of temperature with location in the spacecraft, and with time, was needed. The heat-flow equation (6) can be expanded to include the interactions of thermal masses and the dynamic effects:

Fig. 2—Insulation.

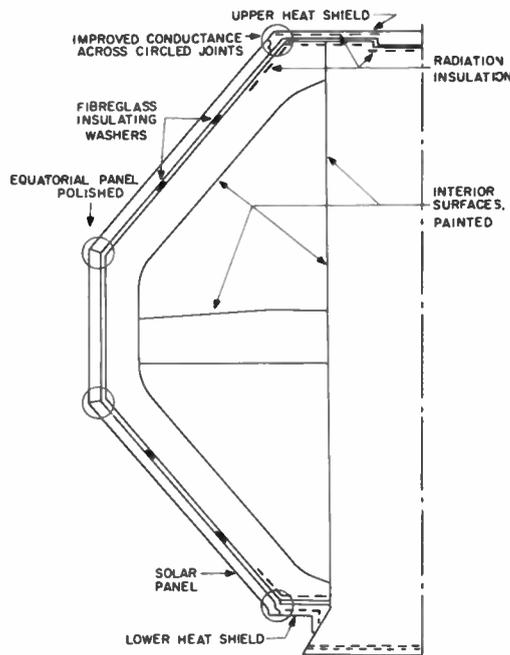
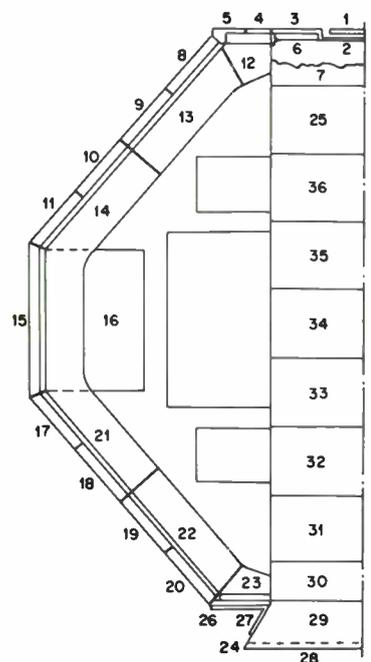


Fig. 3—Nodal divisions.



		α MIN	α MAX	ϵ	$\frac{\alpha}{\epsilon}$ MIN	$\frac{\alpha}{\epsilon}$ MAX
END PLATES	86% EVAPORATED ALUMINUM	.10	.15	.025	.81	1.27
	14% WHITE PAINT	.20	.35	.85		
EQUATOR	POLISHED ALUMINUM	.15	.25	.03-.04	3.7	8.3
SOLAR PANELS		.735	.77	.7	1.05	110

Table II—ISIS A—surface properties.

$$M_i \frac{dT_i}{dt} = A_i \alpha_i (1 - \eta_i) [S^{(i)} \beta_i^{(i)} + R^{(i)} \gamma_i^{(i)}] + A_i \gamma_i^{(i)} \epsilon_i E^{(i)} + P_i' - \kappa_{ij} (T_i - T_j) - A_i F_{ij} \sigma (T_i^4 - T_j^4) - A_i \epsilon_i \sigma T_i^4 \quad (7)$$

The equation is one of a number of first-order non-linear simultaneous differential equations with variable coefficients. This equation assumes that the solar cells have a constant conversion efficiency, which is approximately true if there is no overcharge limiter. On Isis A there is no overcharge limiter except in certain failure conditions.

A set of equations similar to Eq. (7) can be solved numerically. If the variable coefficients change cyclically with time, the numerical procedure is iterative; if the initial conditions are unknown and the steady state for a given environment is sought, the calculation is again iterative. If the starting conditions are known, the temperature-time history can be followed. The calculation method is to start with a set of temperatures and calculate the resulting heat fluxes. From these, the rate of change of temperature with time can be found, and so the new temperatures at the end of the short time interval can be used for the integration.

A computer program was written to solve these equations. It has capacity for

100 nodes, each connected to all the other by conduction and radiation. The program can be used for predicting:

- 1) temperature distribution in a spacecraft;
- 2) temperature distribution in a piece of electronic equipment in vacuum; and
- 3) temperature distribution of a spacecraft during thermal vacuum and solar-simulation testing.

The spacecraft can have time-varying earth-infrared and albedo inputs, solar and earth aspect ratios, and payload heat dissipation. It can be spin stabilized, gravity gradient stabilized, or programmed for an arbitrary sequency of orientations. Active open-loop or closed-loop temperature control can be simulated, where surface properties change at pre-set times or temperatures. It follows that the program can be used for many different types of spacecraft employed in various missions. The use of this program showed that three types of insulation had to be added for high thermal resistance between the exterior "polar regions" and the thrust tube (Fig. 2). A heat shield was added over the end decks, with the annular slot antenna in the center. The surface properties of the heat shields were kept the same as the decks were previously. Radiation insulation blankets were added as shown in

Fig. 2. They are made up of many layers of aluminized mylar, crinkled to minimize the contact areas between layers, and so eliminate the need for fiberglass spacing sheets which were used in previous designs. Fiberglass insulating washers are fitted between the panels and ribs.

To simulate this design, 36 nodes were used (Fig. 3). With these subdivisions, the estimate of internal radiative heat flux becomes important. The problem is greatly simplified by painting all internal surfaces, thus providing them with an infrared emissivity of about 0.85. Hence emission is diffuse, reflections are assumed zero, and all that remains is the calculation of the radiation interchange shape factors. Painting all exposed inside surfaces also reduced thermal resistance from the thrust tube to the shell and the effect of variations in payload heat dissipation.

The final surface was defined as in Table II. These finishes are assumed to be relatively stable in space, with the amount of expected variation shown as a tolerance on absorptivity.

Absorptivity variations in solar panels are not as well known as the variations in white or black paint or polished or evaporated metals. This is partly because a solar panel is a complicated composite surface. For the surface finishes of Table II, the calculated temperature extremes are now -5°C to $+40^\circ\text{C}$. These extreme temperatures occur in different orbital situations. The 40°C case is 100% sun, maximum albedo, maximum power, with the spin axis pointing at the sun. The -5°C case is 66% (minimum) sun, minimum power and albedo, with the spin axis pointing at the sun. The variation in each orbit is shown in Fig. 4. The effect of the albedo radiation on the cold side of the spacecraft can be seen clearly.

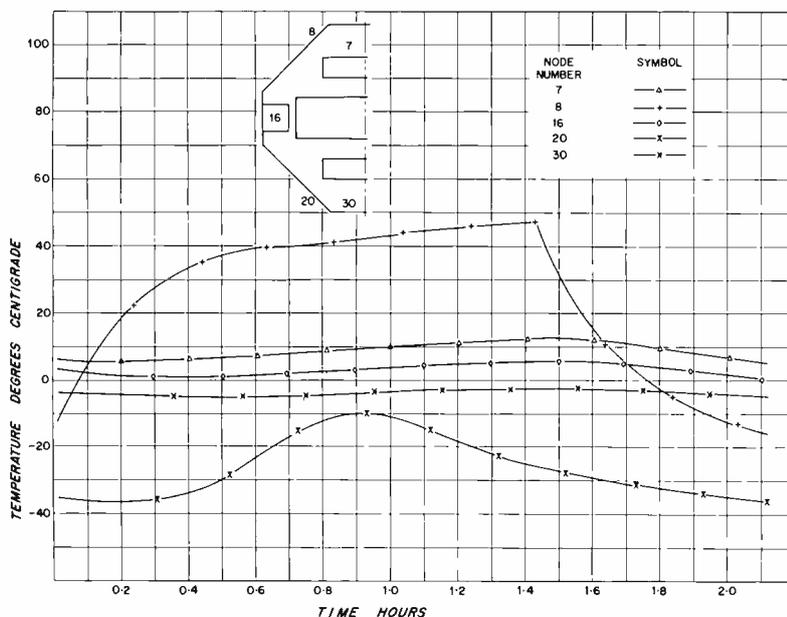
The heat fluxes used in temperature estimates are found using computer programs which calculate percent sun, earth albedo radiation, and infrared radiation with respect to time.

Quadratures for radiation coupling coefficients were evaluated numerically using an IBM-7044 digital computer. The spacecraft is assumed to be a cylinder contained inside a sphere as shown in Fig. 5. Radiation heat exchange between two surfaces in a black enclosure is a function of the surface temperatures and a geometric shape factor. The shape factor between two area elements is given by:

$$dF_{ij} = \frac{\cos \beta_i \cos \beta_j dA_i}{\pi L^2} \quad (8)$$

where β_i and β_j are the angles between the area element normals and the line L joining the two area elements. Integra-

Fig. 4—Minimum sun temperature history.



tion over the two areas yields the exchange factor between the two finite areas. The equation in Fig. 5 gives the interchange integral equation between thrust tube and external panels. Additionally the interchange factors are required for nodal areas of panels since they "see" each other and themselves. For this case, the shape factor between two circumferential segments of a sphere is simply:

$$\frac{\phi_a}{2\pi} (\cos \theta_{JA} - \cos \theta_{JB}) \quad (9)$$

where θ_{JA} and θ_{JB} are the values of θ which define any area A_j (Fig. 5). This stems from the fact that any finite area inside a sphere A_j , 'sees' all other area elements under the same solid angle.

The same method of numerical temperature prediction has been applied to some electronic boxes in the spacecraft e.g., the converter box. If the battery short circuits, this converter must dissipate 18 watts. The simulation was done by assuming a radiation sink temperature to correspond to the average interior temperature of the spacecraft, and a conduction sink temperature corresponding to the average thrust tube temperature. Sixteen nodes are used to make a numerical model of this box. The two transistors mounted on the flange, which is integral with the base, produce the heat. Hence, the main heat path is through the base to the thrust tube. However, the alternative paths to the sides and top of the box, and to the spacecraft shell by radiation, have an appreciable effect on the design. This type of analysis is used to decide the thickness of the flanges and base of boxes which are required to dissipate a large amount of heat.

Launch Window Temperatures

The launch window is set by dynamic and thermal considerations (only the latter being considered here). A certain range of "percent sun" is permissible; thus, a program has been written to calculate percent sun for a launch at any time during any day of the year. This is a calculation of the points of intersection of the orbit plane with the earth-shadow cylinder, and the corresponding time in shadow, for the full range of possible launch times.

Ascent heating has to be calculated, to see what combination of times spent in sun and shadow are necessary for the spacecraft temperature to stay within specified limits. The ascent heat calculation is in three parts: 1) the heat fluxes from the earth and sun with corresponding view factors, 2) aerodynamic heating, and 3) calculation of heat fluxes and temperature within the spacecraft.

The earth and solar heat flux calcula-

tions are similar to those already described for inputs to an orbiting spacecraft. The solar aspect ratio is now a function of the time of day, the day of year, and the position in the launch trajectory. As the spacecraft may not be spinning for some time after shroud release, it is necessary to calculate solar and earth aspect ratios without assuming axial symmetry. This means a large number of nodes must be used to describe the circumferential and axial heat flow.

The aerodynamic heating considered is in the free molecule flow region only as, in general, the spacecraft is protected by a shroud until this region is reached. The equations governing the heat transfer are:^{6,7}

$$\frac{\bar{Q}}{CN\sigma T_{au}} = \frac{\gamma' + 1}{2\gamma' - 2} (\bar{G} + \bar{F}) \frac{T_w}{T_o} - \left(s^2 + \frac{\gamma'}{\gamma' - 1} \right) (\bar{G} + \bar{F}) + \frac{\bar{G}}{2} \quad (10)$$

The computer program for this calculation will include the 1959 ARDC Model Atmosphere, and the input will include a description of the launch trajectory. At shroud separation, spacecraft temperature distribution is known. The radiative earth and solar heat fluxes, the earth and solar aspect ratios, and the free molecule flow heating (which is dependent on the spacecraft temperature and velocity, and the local atmospheric properties) are calculated. This information will then be fed into the multi-node thermal program, which will calculate new temperatures for the next time interval. This will be repeated, providing a history of temperature with time for each node.

THERMAL TEST PROGRAM

The test program to check out the spacecraft thermal design involves three main activities. In the first check, exterior surface finishes are selected by spectral reflectance measurements. Where necessary, samples are exposed to ultraviolet radiation to investigate possible changes in solar absorptivity. For the solar panels, it was not possible to use the spectral reflectance technique because of their size (approximately 18 inches square) and the composite surface. The surface area is made up of 74% solar cells covered by adhesive, cover glass, filters, and an anti-reflective coating; 13% sandblasted aluminum; and 13% black RTV. The solar absorptivity and infrared emissivity of this panel was measured in a solar simulation chamber at Goddard Space Flight Center. As a result of those tests, the panel surface was modified by covering an exposed area of epoxy glass with black RTV and changing the existing white RTV to black. Subsequent to this, it has been discovered that the RTV used (CE-511 and CE-577)

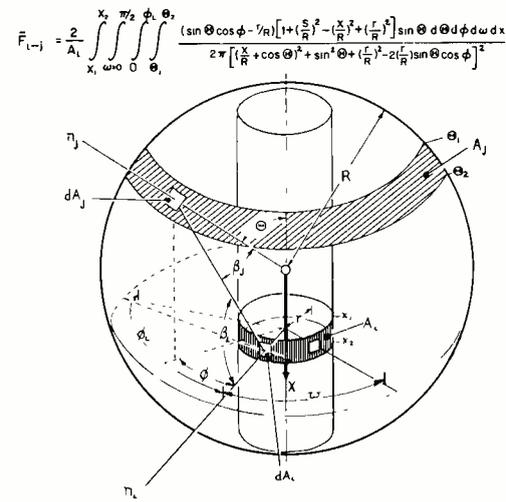


Fig. 5—Internal shape factors.

gives off up to 5% by weight of silicon oil in vacuum. Temperature cycling techniques to minimize this outgassing are currently being investigated. Meanwhile spectral reflectance measurements on polished aluminum coated in silicon oil are being conducted to establish the effect of the silicon oil on the thermal design.

The second type of thermal testing which has been undertaken is to investigate regions in which the heat flow paths are doubtful. One region of doubt is where sheet metal or thin sections are bolted together. The only satisfactory method of establishing the contact thermal resistance value is by measurement. This has been done on a sample solar-panel-to-equatorial-panel bolted joint. The effect of adding indium foil was measured, and it was found to be an appreciable advantage. The test was done by measuring heat flow and temperature drop across a joint in vacuum.

The thermal design will be acceptance tested in a solar simulation facility at Goddard Space Flight Center. This will check out the spacecraft at the extremes of orientation and percent sun. The resulting spacecraft temperatures will not be directly representative of what is expected in space. As a result, spacecraft temperatures in the solar simulation chamber will have to be predicted, and compared with measured results.

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LABORATORY STUDIES OF SATELLITE DESIGN PROBLEMS

This paper considers some of the satellite engineering problems and constraints which develop as a consequence of the orbital environment, the experiments, and portions of the spacecraft system. With reference to topside sounding satellites such as ISIS A, potential problems associated with spacecraft geometry, solar-cell panels, DC-to-DC converters, and the experiments themselves are discussed. These problems have been studied under scaled laboratory conditions, contributing design information on alleviation techniques where necessary. Other uses of simulation in this area are indicated.

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IN considering a spacecraft to be used as an earth satellite for scientific investigations, the various design areas may be conveniently classified under five very general headings:

- 1) Mechanical provision for experiments;
- 2) Communications system for command and data transmission;
- 3) Power;
- 4) Spacecraft orientation (attitude) monitoring and usually control; and
- 5) Spacecraft environment.

The first four of these classifications involve what may be termed (for the purposes of this article) conventional space engineering; the last classification—the problems associated with the environment—includes many problems that are also the province of the engineer: thermal balance throughout the vehicle, behavior of components under space conditions; environmental changes during launch. As a subdivision within this general classification, however, there are many potential problems arising from the satellite motion through a tenuous

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magnetoplasma, i.e. through an electrically neutral system of positive and negative charged particles (usually positive ions and electrons) that includes an associated magnetic field. Such problems are generally within the realm of the plasma physicist.

Since the satellite is moving through a magnetoplasma, interactions between the two will occur, which may have deleterious effects. These interactions will usually give rise to some form of plasma sheath about the vehicle, i.e. a region wherein the plasma is perturbed.

As an illustration of this effect consider what happens when a body is placed in a plasma. The plasma consists of (generally) positive ions and electrons. These particles have equal energies and, since there is a large discrepancy in their masses, this means that the electrons have, by comparison, a very high mobility. Thus, more electrons will strike the body than positive ions. Since the body is not allowed to act as either a source or a sink for electric charge, the electrons build up a negative charge just sufficient to decrease the flow of further electrons so that it equals and cancels the ion flow, and equilibrium is established. However, the potential of this electrically floating body is now slightly negative with respect to the plasma (i.e. the 'floating potential' is negative with respect to the 'plasma potential'). The decrease in the electron flow caused by this potential difference, or electric field, means that the region around the body has fewer electrons than the normal plasma.

Now it can be seen that if this body has some form of plasma measuring device mounted on its surface, it is possible for this diagnostic to monitor the conditions prevailing inside the plasma

sheath, instead of measuring the parameters of the ambient plasma.

Generally speaking, a sheath such as that described is of small dimension and it is possible to design diagnostic devices such that they effectively probe through and investigate conditions beyond the sheath. However, it must be appreciated that the situation described, though accurate in itself, is very much a simplification of the satellite situation. Consider a small spherical satellite in earth orbit in the upper ionosphere. First it may be said that the vehicle will be surrounded by a 'floating' sheath, as described above. However, since the body is now a satellite, account must be taken of the high relative velocity between the satellite and the plasma. Usually this velocity is high with respect to the ion thermal velocity (at least for near earth orbits) and low with respect to the electron thermal velocity. Thus the front surface of the satellite 'sweeps up' a 'ram current' of ions, leaving a complex wake in the rear of the vehicle, and so modifying the simple sheath picture. To this picture must be added the effects produced by the interaction of the moving, conducting satellite with the earth's magnetic field **B**.

These effects become most pronounced when the satellite velocity vector **V** and the magnetic field **B** are perpendicular, when an electric field **E** is produced perpendicular to both **V** and **B** (the **VxB** effect). This produces a sheath analogous to the floating sheath, but since the potential difference between the body and the plasma now varies across the surface of the body (parallel to **E**) the sheath so formed also varies.

It must be realized that none of the above sheaths are produced as a steady phenomenon, but rather as effects which vary depending upon variations in a number of parameters including satellite orientation, magnetic field, and velocity.

LABORATORY EXPERIMENTS

The two experiments to be described both deal primarily with aspects of the **VxB** sheath: in the first instance, a technique is developed whereby the effects of the sheath on measuring equipment can be minimized; in the second, it is shown how this **VxB** effect can lead to interference in the operation of the spacecraft.

VxB Effect

Since this work was performed for the Defence Research Telecommunications Establishment of the Defence Research Board of Canada, the interest was biased towards the problems of the Canadian satellites of the ALOUETTE and ISIS series. The primary experiments associated with these satellites are the sounding experi-

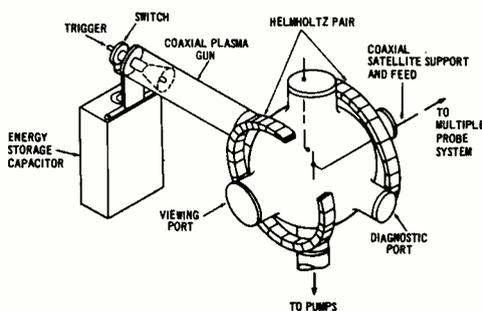


Fig. 1—Schematic diagram of apparatus.

ments whereby the upper ionosphere is investigated by probing with electromagnetic waves (100 kHz to 20 MHz), in a technique somewhat similar to radar. Satellites are used for these measurements because of their mobility and accessibility. Since the upper levels of the ionosphere respond to electromagnetic waves of a frequency which will not pass through the layer situated below these upper levels they cannot be investigated from the ground, and so must be probed from above, or the topside, producing the generic name 'topside sounder' for such satellites. A characteristic of such topside sounder satellites is that they carry very long sounding antennas (Isis A has approximately a spherical body of one meter diameter, and main antennas 36.6 meters long, i.e. ~ 73 m tip-to-tip). Thus, because the total $V \times B$ voltage varies directly as L (~ 70 m for Isis A), even though the magnetic field B may be small, the velocity V is large and under certain conditions of satellite orientation and velocity the total $V \times B \cdot L$ voltage developed can be as much as 20 volts. It can be shown that the maximum potential difference occurs at one end of the antennas. However, a potential difference of 10 volts developed about the middle of the antennas (i.e., on the body) is still sufficiently large that it can produce a sheath capable of disturbing the direct measurement experiments located on or within ~ 1 meter of the body.

Such a situation was studied in the laboratory using an apparatus in which the plasma/satellite interaction is simulated. Models of the satellite were sus-

ended in an evacuated interaction chamber and a plasma produced by a two-electrode coaxial plasma gun was allowed to flow down a flight tube into the interaction chamber and around the model. A magnetic field was produced by a Helmholtz coil arrangement set up external to the interaction chamber, as shown in Fig. 1. Thus, a plasma flow was produced with a magnetic field B arranged to be perpendicular to the plasma velocity vector V , producing an electrical field E perpendicular to both V and B and parallel to the antennas of the model satellite. This arrangement produced the field E in the plasma, leaving the satellite a unipotential body, a situation analogous to the space condition of an electrically field-free plasma and a potential gradient restricted to the vicinity of the satellite.¹

The first consideration with such an apparatus, since it is not a true but a scaled simulation, is how accurate is the scaling? To evaluate this it is necessary to determine first the scaling laws that apply and then determine values for a number of laboratory plasma parameters and compare them with the predictions derived from the scaling laws. These scaling laws were investigated by Shkarofsky² who showed that the plasma parameters required to simulate a typical orbit were a density of $\sim 10^{10}$ to 10^{11} cm^{-3} , at a temperature of < 1 eV, and a velocity of ~ 2 $\text{cm}/\mu\text{s}$ through a magnetic field of ~ 350 gauss. These requirements were met reasonably well.¹

The techniques used to determine the plasma parameters included Langmuir probes to determine the plasma temperature and also, from a variation in the floating potential across the stream, the $V \times B$ field; 9-GHz microwaves for the variation of plasma density with voltage on the plasma gun; and, using a gaussmeter to measure the magnetic field, the previous electric-field measurement was used to measure plasma velocity.

Having established the parameters of the pulsed plasma stream and ensuring that they met the scaling requirements, the model satellite (consisting of a spherical body with two extended antennas) was placed in the interaction chamber. Considering the Langmuir characteristic of the plasma and assuming the satellite to act in an analogous fashion led to the conclusion that a bias voltage applied between the body and antennas would minimize the sheath problem in the body region (Fig. 2). For simplicity, the body and the antennas are considered to be of the same cross sectional area. The varying potential difference between the body and the plasma, represented by the abscissa, is considered as a gradient along the body, and the current density



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MICHAEL KASHA received the B.Sc. in Physics (Honours) in 1957 from London University. After a short time as a Lecturer in Mathematics and Physics at the Harrow Polytechnic, he joined the United Kingdom Atomic Energy Authority (UKAEA) at Harwell, to work in the Controlled Thermonuclear Reactions Division. There he was engaged on plasma physics studies, working on the Spider experiment, an investigation of shock waves in a plasma. This work entailed the design, construction and operation of 40 kV, 20 kilojoule device. In 1961 he transferred to the Culham Laboratory of the UKAEA, to work on Taranfuta, a similar experiment using a 100 kV, 100 kilojoule machine. He was concerned with the development of a 100 kV, 1.4 million ampere fast-acting (20 nsec) switching system and various other aspects of the design and construction. He devised and developed various diagnostic devices (e.g., multicoil magnetic probes, optical interferometers, and time resolved spectrometers). Mr. Kasha joined the Research Laboratories of RCA Victor Company, Ltd. in 1964, since which time he has been engaged in studies of satellite interaction with the ionosphere. He is an Associate of the Institute of Physics in London.

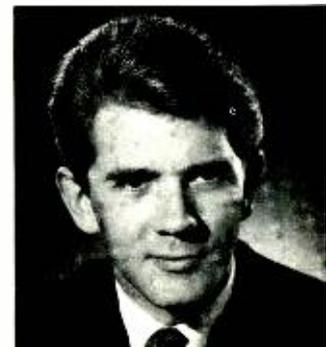
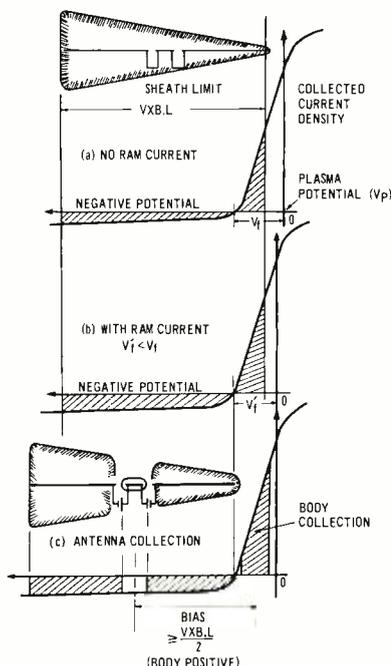


Fig. 2—Langmuir probe analogy.



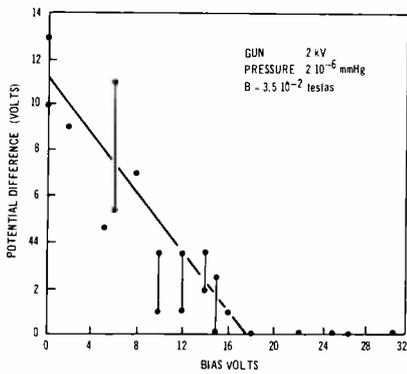


Fig. 3—Variation of plasma/vehicle potential difference with bias.

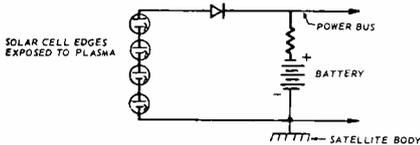


Fig. 4—Power supply.

collected at each part of the body is represented by the ordinate (electron current shown as positive). The addition of a ram-ion current, caused by the 'sweeping up' of ions discussed previously, has little effect on this curve.

It can be seen that the smallest sheath is associated with the smallest body/plasma potential difference, and with the electron collection region. Thus a bias applied as shown, causing the body to become the electron collecting portion of the system, should ensure that the body has the smallest sheath

To test this concept, a model satellite was constructed so that a variable potential bias could be applied between the body and the antennas. As was mentioned above, the plasma sheath is associated with the potential difference between the plasma and the body, and so this was used as a diagnostic for the sheath. The plasma potential (in fact 'floating' potential) was measured by a probe located in the plasma, near the model but outside any possible sheath effects. This potential was measured and compared with the potential of the body of the satellite. The difference between them was plotted as a function of the body/antenna bias (Fig. 3), and it can be seen that this difference goes to zero, signifying a minimum sheath for a bias ≥ 18 volts which corresponds to $V_{xB} \cdot L/2$ as predicted in Fig. 2.

The experiment thus shows that the bias concept is effective, and calculations of the DC-to-DC converters used on the given in Osborne and Kasha¹ show that the system is easily applicable to a satellite of the ALOUETTE or Isis type, for a very small power cost (~ 20 mW). This technique is being applied in the Isis A spacecraft.

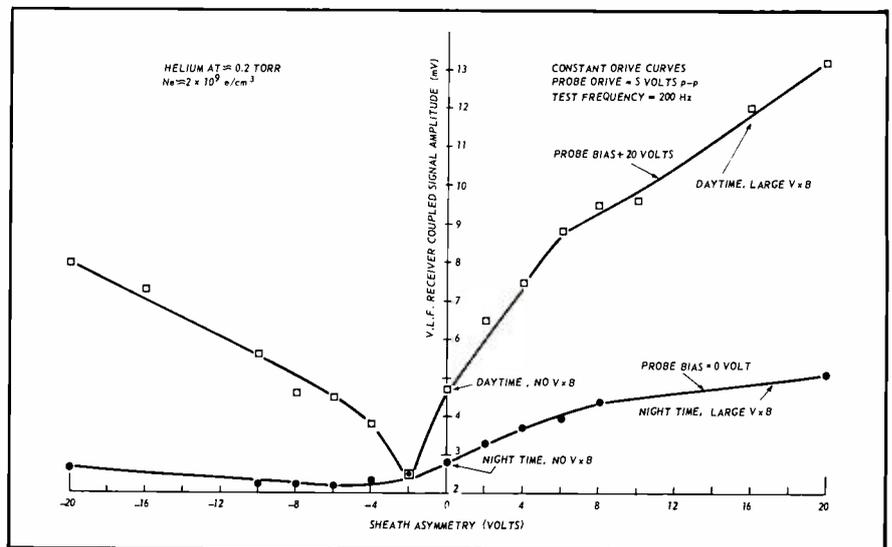


Fig. 5—Plot of VLF 'coupled signal amplitude' versus sheath asymmetry voltage and probe bias, under constant amplitude probe drive voltage.

VLF Interference

Analysis of the output of the VLF receiver on ALOUETTE I showed the presence of signals at the frequency (and harmonics) satellite power supply. This is an obvious form of interference but, since it has been observed to mix with the natural signals and form combination tones, and since the level of the automatic gain control of the VLF receiver can be set by the level of interference signals, it is virtually impossible, at times, to discriminate between the true signal and the interference, or even to know the correct signal level when this discrimination is possible. Inductive interference, or 'pick-up' is of course a common problem in circuit design of all kinds, and this was borne in mind during the design of the satellite system, and was moreover checked out before launch, when it was found to be detectable, but at a level considered to be not important. It appears that the interference really developed when the satellite was in orbit. It must also be noted that this interference did not occur at a constant level, but showed a definite variation. Examination of the data from the ALOUETTE led to certain patterns being established for the behaviour of this interference: variations associated with satellite being in the dark or light part of its orbit with a sharp discontinuity at satellite dawn, and also variations which could be linked to the satellite orientation with respect to a plane defined by the satellite's velocity vector and the earth's magnetic field, i.e. a possible dependence on the presence of a V_{xB} effect. Such patterns led to the conclusion that the interference was in some way associated with the plasma around the vehicle, and hence a possible mechanism, based on such an assumption, was developed and tested.

Specifically, any proposed solution had to explain the following observations:

- 1) With the satellite in the dark, aligned so that no $V_{xB} \cdot L$ potential gradient exists along the antennas, no converter interference is found in the VLF receiver output;
- 2) With the satellite in the dark but with V_{xB} gradients, negligible effects were noted;
- 3) With the satellite in the light but no V_{xB} , no interference; and
- 4) With the satellite in the light and aligned for a V_{xB} gradient, large interference signals are found.

Fig. 4 shows a simplified power supply system for ALOUETTE I. A series-parallel array of solar cells with their terminals exposed to the surrounding plasma supply (via a diode) power to the batteries and various satellite systems. Where the power supply impedance is not zero, the chopping frequency of the electrical DC-to-DC converter will appear on the main power bus. Now when the satellite is in the dark, the solar cells are at the body potential and the diode is biased off to prevent battery drain, and so any AC signal on the power bus is unable to reach the solar cells. When the satellite is illuminated, however, the diode has a low impedance, allowing the converter signal to appear across the solar cells, which are now raised to various positive DC potentials. It remains to determine how this signal will appear on the VLF receiver antenna with V_{xB} modulation.

The VLF receiver antenna is a large dipole, coupled via a transformer, to the VLF receiver in such a way that any alternating current of the appropriate frequency passing through the transformer between the two halves of the antenna, or unequally between each half antenna and the satellite body, will appear at the VLF receiver input. Now a satellite

can have associated with it asymmetric $V \times B$ plasma sheaths, in such a way that all the electron collection required to keep the system electrically floating takes place at one point, usually one end of the antenna array (Fig. 2). Now if there is an AC signal on the exposed edges of the solar cells, which are themselves raised to a positive potential by their operation, the solar cells will collect a varying electron current. Then, to maintain the floating condition, a variation of opposite phase must occur in the electron current collected on the antenna, which immediately introduces an asymmetric signal through the transformer to the body, as discussed above, and consequently introduces an interference signal at the input of the VLF receiver. In the light of this proposed mechanism, consider now the four conditions previously set forth.

- 1) Satellite in the dark, with no $V \times B$ gradient: no converter signal is present on the cells since the diode is biased off. Any residual signal would affect the antennas symmetrically and there is thus no interference at the receiver.
- 2) Satellite in the dark, with $V \times B$ sheaths: The $V \times B$ gradient is such that the body (and cell) potential is approximately $V \times B \cdot L/2$ below the plasma potential and the AC signal is not sufficient to raise the solar cell potential into the electron collecting region, and thus the cells are free to change their potential without affecting the current collection pattern.
- 3) Satellite in the light, but no $V \times B$ effects. The solar cells are now at a positive potential, and so a variation of electron collection develops on the antennas, but it does so symmetrically and so no interference is found.
- 4) Satellite illuminated and suffering $V \times B$ potential gradients produces the correct asymmetry for the converter signal, to affect the electron collection and thus induce a modulation in the electron current collected by one antenna and so produce an asymmetric signal which can appear at the VLF receiver. The converter signal appears on the exposed edges of the solar cells which are now at a large positive potential with respect to the plasma potential.

Such a situation was simulated in the laboratory, where an equivalent satellite system, effectively containing a transmitter transformer, antennas, variable $V \times B$ antenna sheaths, and an exposed solar cell terminal (which could be raised to a DC potential and have impressed upon it a converter signal) was placed in a stationary helium plasma. The results of this simulation are shown in Fig. 5 which shows the magnitude of the detected interference signal for the four conditions discussed above. The lack of symmetry and the fact that the minimum does not occur at zero $V \times B$ potential are due to inherent coupling introduced by the model and circuitry

unbalance. Such a picture illustrates well the operation of the proposed mechanism, and agrees well with the spin modulation data from the satellite.³

SUBSIDIARY WORK

The previous section has dealt in some detail with two laboratory investigations of satellite/plasma interactions to give some idea of the method of approach used and the techniques employed by the plasma physicist in dealing with such problems. The techniques can of course be applied to a broader field than that implied by the above examples.

Kasha and Johnston⁴ have used very similar techniques to investigate the response of a plasma diagnostic device mounted on a satellite as a function of satellite orientation. A gold plated sphere was used to simulate a satellite, with a total current monitor, or collector, mounted on the surface, the whole being situated in a pulsed flowing plasma. By rotating the sphere around an axis perpendicular to the plasma velocity vector, the response of the current monitor was determined as a function of satellite orientation in such a manner that the effects of the ram current and the wake found behind the simulated vehicle could be clearly seen. As a further experiment a magnetic field was produced over the volume of the plasma stream/satellite model region, parallel to the axis of rotation of the model. This produced a $V \times B$ potential gradient effect which was now superimposed onto the previous response curve. This second response curve, now highly asymmetric where before it had been symmetric about the plasma velocity vector, was determined experimentally, and found to compare well with that of the EXPLORER VIII satellite.

Other aspects of this satellite work have included a study by Graf and Jassby⁵ of the behaviour of antennas in a plasma. The impedance of an antenna is usually determined by its geometry and the dielectric constant of the surrounding medium. Should this antenna be mounted on a satellite, it will find itself in a plasma, i.e. a medium whose dielectric constant may change, either with antenna position (different locations within the satellite orbit) or time. Obviously such changes will bring about changes in the antenna impedance which are related to the plasma parameters.

Such studies as this are useful both to the engineer, since they illustrate such phenomena as a varying antenna impedance, and to the physicist, since they indicate new methods for determining the parameters of the space plasma.

At present the RCA Victor Research Laboratories are conducting some pre-

liminary investigations into the phenomenon of 'transmitter-induced sheaths'. These plasma sheaths are formed around transmitting antennas under the influence of the antenna operation, i.e. the presence of a pulse of varying high voltage. The main point of interest is not so much the creation of such sheaths, but the prospects for their persistence once the generating signal has been removed, since they can be of such magnitude as to seriously perturb the operation of the satellite or its experiments. The sheaths, and their relaxation times, are found to depend markedly on the transmitter frequency and on the ambient plasma. Preliminary results indicate that it may be possible for the relaxation time, under certain conditions, to overlap the time period when the local-plasma diagnostic experiments may be activated, a time of the order of a millisecond. The determination of these relaxation times is complicated by the internal circuitry of the particular satellite under consideration and therefore the study is being continued with the aid of an equivalent circuit, with which it is hoped to simulate, though not directly, the action of the ram ion currents, electron currents, etc.

CONCLUSION

In this article one of the parts played by the plasma physics laboratory in the essentially engineering problem of designing a satellite has been described. It can be seen that the general approach adopted in the laboratory to these problems is that of simulation, either direct or scale model experiments. The particular scaling laws that must be used for such experiments have been well established, and the techniques that are used to produce plasma of the correct, scaled parameters are being continually improved. Indications have also been given as to the various other fields where work has been, or is, being performed with a view to acquiring a greater understanding of the interactions that occur between a fast moving satellite and the ambient magnetoplasma.

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ELECTRICAL AND MECHANICAL DESIGN OF THE MILL VILLAGE ANTENNA-RADOME COMPLEX

Requirements for a satellite communication ground station must be determined from the optimum conditions of the global ComSat system. The most important characteristic is the gain-to-noise-temperature ratio (and its fading) which must be optimized for a given cost. Additional requirements are the compatibility with other ground stations, communication reliability, minimum design risk, easy operability and maintainability, low operational cost, and long life. Special requirements were presented for the Mill Village station by the Canadian environment. This paper discusses the electrical and mechanical design of the inflated radome and antenna. The system has full-angle and polarization tracking capability, including orientable linear polarization. The system has been built and has met all the original design and communication performance objectives.

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EVER since the usefulness of micro-waves for point-to-point communications was recognized, designers have searched for large antenna gain at economical cost. The advantage of large gain as a means of reducing transmission losses was obvious; nevertheless (for economical reasons), the desired antenna gain had to be balanced with the subsystem characteristics of the entire network. Thus, the development of communication antennas was limited not only by their own problems, but by the characteristics of the related equipment.

INITIAL MILL VILLAGE ANTENNA DESIGN CONSIDERATIONS

Orbiting satellites, carrying at least one of the repeater stations, removed the larger part of the propagation path from the vicinity of atmospheric and ground-noise sources. In the case of the down link, the inherent geometry eliminated most of the background radiation from the sensitivity region of the ground-based receiving antenna. The drastic reduction of external noise levels gave tremendous impetus to the development of compatible low-noise antennas and receivers. Under these new circumstances, the antenna gain (G) was no

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longer the overwhelmingly important characteristic, and the gain-to-system-noise-temperature ratio (G/T_s) was introduced.

Usually, the occurrence of a new problem is followed by an early solution based more or less on brute force methods. Earth station antennas were no exception, and some large-gain, low-noise antennas were built, where economy (though important) was of secondary consideration. However, the situation quickly reversed, and new characteristics were defined to measure the cost effectiveness of the design. This effectiveness can be expressed as the G/T_s ratio relative to the weight of the antenna.

During the past decade, the state-of-art in satellite communication has favored a large ground antenna, close to 60-dB gain. The frequency bands have to satisfy the following conditions:

- 1) for reception—giving minimum combined atmospheric and galactic noise radiation; and
- 2) for transmission—high enough to permit adequate receive-transmit isolation and low enough to avoid excessive antenna tolerance problems.

When hemispherical angular coverage and high-precision tracking (1/10 of the 3-dB beamwidth) are added to the

above defined requirement of effectiveness, the possible antennas are reduced to a very limited number.

In these antennas, without exception, the large aperture area ($\approx 6000 \text{ ft}^2$) is realized by a parabolic reflector illuminated by a spherical wave. The effectiveness of such an antenna is determined by the shape of the main reflector. As the cost of the large, precision reflector and its associated structure is usually far more than the cost of the source (feed system) a great effort went into the design of source systems which produce nearly ideal aperture distributions.

In a global communication system with many satellites and earth stations, the standardization of the G/T_s ratio is highly desirable. Thus, effective radiated power of the satellite can be selected optimally to obtain economical advantages in the construction and operation of Earth stations.

EARTH STATION OBJECTIVES

In 1963, the Canadian Department of Transport decided to build, for Canada, an experimental earth station terminal. The declared objectives of the station were:

- 1) Create a tool by which specifications and design data for operational ground stations can be generated;
- 2) Permit participation with other nations in satellite communication experiments;
- 3) Aid participation with other nations in the development of international operating procedures and standards;
- 4) Develop Canadian knowledge in supplying operational earth stations for Canada and for international market;
- 5) Train staff for operational use; and
- 6) Conduct experiments on various hardware units and system aspects in order to permit adaptation of the station for future operational use.

RADOME-ANTENNA REQUIREMENTS

On the basis of the above considerations, the following requirements were established for the antenna.

- 1) Frequency Band—3960 to 4200 MHz receive, 6160 to 6400 MHz transmit. In actual practice, these frequency bands (limited by the feed system only) were exceeded by a fair margin.
- 2) Gain—More than 58 dB (in the receiver frequency band) to assure 600 voice channel or one color-tv channel capability, with currently used satellite power. (The gain achieved was approximately 1-dB higher).
- 3) System Noise Temperature—Less than 65°K at 7.5° elevation above the horizon at 4GHz in clear weather. The measured value on the completed system was a few degrees better than the specification.
- 4) Angular Tracking—Tracking is generally characterized by angular coverage, accuracy, speed, and acceleration.

TABLE I—Measured Antenna Gain of the Mill Village Antenna System

<i>f</i> (GHz)	Gain (dB) factory	field
3.9	58.6	58.0
4.0	59.0	59.1
4.1	59.1	59.2
4.2	59.3	59.4
6.0	61.2	59.9
6.1	61.2	60.6
6.2	61.1	59.6
6.3	61.5	59.7
6.4	61.2	59.6

TABLE II—Calculated and Measured Antenna Noise Temperature Versus Elevation Angles

Θ (degrees)	Noise Temperature ($^{\circ}$ K)	
	Calculated	Measured
90	28.0	34.2
60	28.5	33.8
30	29.5	36.1
10	39.0	44.0
7.5	41.5	47.6

$f = 4081$ MHz

The smallest angular coverage, and minimum speed, are required for synchronous satellites. For medium-orbit satellites, full beam steering capabilities are desirable. Therefore, tracking speeds and accelerations were specified according to these types of satellites. The rms tracking accuracy had to be less than $\frac{1}{10}$ of the 3-dB beamwidth to make tracking loss negligible (equivalent to about 0.02°).

- 5) Polarization Matching—To avoid excessive signal loss, the polarization of the "receive" antenna had to be matched to the incoming polarization. Similarly, the transmitter antenna had to be matched to the "receive" polarization of the spacecraft. Generally, orthogonal polarizations were needed between transmit and receive modes to obtain additional isolation between these frequencies. Changeover time from circular to linear polarization was not critical, but alignment of the attitude of linear polarization had to be instantaneous.
- 6) Weather Protection—The ideal weather protection is a function of the site, but generally the effects of weather cannot be completely eliminated. The magnitude and time distribution of the weather-originated fading (about 3 to 6 dB) can be influenced by the type of antenna protection. In systems under radomes, the main source of fading is precipitation, while in systems without radomes, the main sources are precipitation and wind. The choice of radome-protected or exposed antennas was not clearcut on the basis of G/T_e ratio; the choice was based on operational and life-time considerations.

ANTENNA ELECTRICAL DESIGN

Effectiveness of the antenna system as previously defined is maximum for symmetrical structures (axially symmetrical

paraboloid) which are the most commonly available design. Therefore, it was decided to tailor the rest of the optical system to fit this arrangement; furthermore, the choice of a far-field Cassegrainian feed system was selected on the basis of its advantages in equipment layout, simplicity, and high G/T_e ratio (Fig. 1).

When the Mill Village program began, an RCA experimental feasibility study of a multimode wideband tracking-communication feed had been completed and was the basis of the hardware design. The requirements of the feed (radiating source, Cassegrainian subreflector, and supporting frames) were as follows:

- 1) Optimum performance-to-cost ratio for the antenna complex (performance is characterized by ratios of antenna gain to noise temperature);
- 2) Minimum of microwave component types;
- 3) Large flexibility in operational modes, and coverage of a wide frequency band to accommodate possible changes of frequency requirements;
- 4) Low circuit loss and difference-mode minimum depth by using highly symmetrical waveguide cross-sections;
- 5) Good aperture field distribution for the main reflector in the receiver frequency band, while maintaining at least -3 -dB antenna efficiency in the transmitter frequency band;
- 6) Freedom for field alignment of the feed relative to the main reflector; and
- 7) Both circular and orientable linear polarization.

The first requirement virtually dictates the use of some form of Cassegrainian system, in which the radiating source first illuminates a primary reflector, reflecting the wave toward a secondary reflector. In the simplest form of Cassegrainian system, the radiating source aperture is small and the subreflector is in its far field. Then the subreflector is a symmetrical hyperboloid and the secondary reflector is a symmetrical paraboloid. Mechanical symmetry results in the simplest construction and minimum weight. An 85-foot-diameter solid paraboloid with a focal distance of 36 feet and RMS surface tolerance (half-path-length error) of less than 0.040 inch was selected for the main reflector. Such a paraboloid is easily fabricated and has known mechanical characteristics; it represents a good compromise among weight/aperture-area ratio, rigidity, and weight of feed-support structure.

To illuminate a relatively flat paraboloid with low spillover, requires an illuminating aperture of ten or more wavelengths. Therefore, an 8.5-foot-diameter hyperboloid subreflector with a focal distance of 18 feet was used.

The radiating source system can be operated in a linearly polarized mode and may be oriented in any plane. In principle, this system is relatively simple and, with the exception of the mode filter, does not contain any radically new elements.

The transmitter (Tx) terminal (wr-159) accepts power up to 10 kilowatts cw. Power is divided into two equal parts; each half travels through a cutoff section and a bandpass filter that provide more than 125-dB attenuation below 4200 MHz, and exhibit less than 0.13-dB attenuation for the Tx frequencies. In addition to these filters, the arm connected to the side output of the source system has an adjustable phase shifter using a short-slot hybrid with non-contacting plungers. The outputs of the Tx bandpass filters are connected to the receiver (Rx) bandpass filters at the junctions (S) and (C); these form the duplexing points, with negligible junction effects. Beyond these junction points, both the center and side-arm transmitter power is divided into four equal parts by identical wideband hybrids. (The four-way power division is necessary to introduce monopulse tracking capability for the receiving band.) After these manipulations, the center power and side-arm power are recombined in a four-port orthogonal coupler that has four square-waveguide outputs. Each of these cross-sections support the TE_{10} and TE_{01} modes corresponding to the center and side outputs of the system. Each of these modes is decomposed in the following symmetrical diamond transformers and converted into a left and right circularly polarized wave by the 90° differential phase shifter that terminates the four-port circuit.

The four-port polarizer launches four individual TE_{10} modes into the mode filter, an oversized square-waveguide section having two basic purposes: 1) match the four-port circuit to the multimode horn, and 2) produce a symmetrically tapered field distribution in the aperture of this horn.

An oversized square-waveguide cross-section capable of supporting the TE_{10} , TE_{11} , TE_{20} , TE_{21} + TM_{21} , and TE_{30} modes was used. This waveguide, approximately 2λ long, has a series of crosses at the input end for matching the sum and difference modes and a series of posts at the output end for pattern shaping. The mode filter is followed by a square horn that has a 5λ aperture size in the transmitting band.

The operation of the system for the received frequencies is basically identical to that for Tx operation, although the direction of propagation is opposite

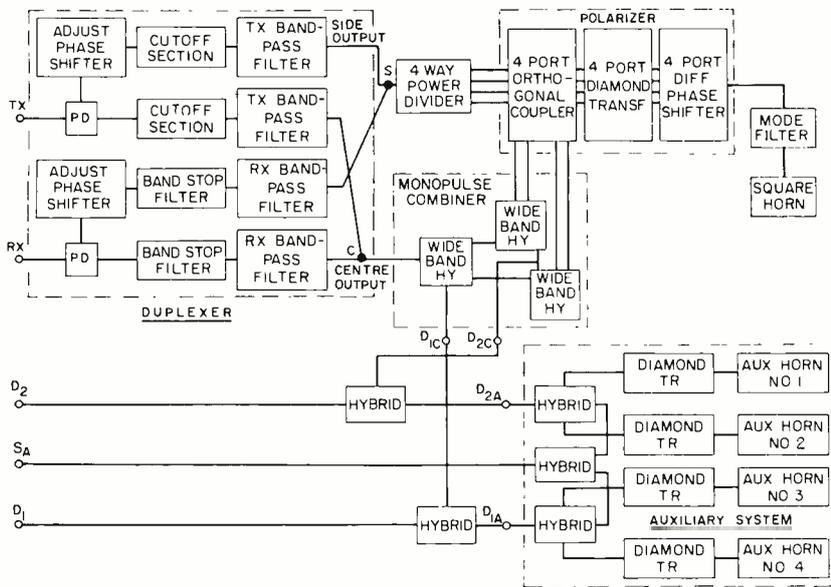


Fig. 1—Block diagram of the feed system.

and band-stop filters are used in the receive arm of the duplexer instead of the cutoff waveguide sections of the transmit arm.

The difference-mode operation of the system is somewhat unconventional, mainly because it combines two independent monopulse systems. One monopulse system is realized in the center multimode system and is obtained through the three wideband hybrids of the monopulse combiner. This system is quite effective, even though the difference-mode aperture is only $\frac{1}{2}$ the optimum value. This limitation is re-

moved by the addition of an auxiliary four-horn monopulse system consisting of four circularly-polarized rectangular horns located symmetrically around the multimode square center horn. The horns are diagonally fed, and circular polarization is achieved by the selection of horn length and aperture aspect ratio.

Conversion of the feasibility design study into operational field hardware took approximately $1\frac{1}{2}$ years. Most of the electrical tests were done in RCA Victor's anechoic chamber, and consisted of amplitude and phase pattern recordings of the radiating source,

vswr and isolation tests at the various terminals, and loss measurements through various channels of the system. All measurements had to be conducted in wide-frequency band, and for various polarization modes and polarization positions. Since no scale model of the antenna was ever built, great effort was maintained to predict the performance of the antenna system after the installation of the feed.

The efficiency, noise temperature, pointing, and tracking accuracy of the overall system were calculated using computer programs. An improvement in state of art was achieved in predicting the final G/T , to within a few tenths of a decibel.

The most important feed system patterns and overall antenna system patterns are indicated in Figs. 2 and 3 respectively. Table I shows the achieved antenna gain. Table II exhibits the noise temperature versus elevation angles for dry weather conditions. It may be noted that the completed system not only achieved the specified gain and noise temperature, but its performance is still unique as compared to 85-ft diameter antennas in the same frequency band.

MECHANICAL CONSIDERATIONS

The antenna and pedestal combination was designed to meet the specific pointing accuracy requirements and natural frequencies, provide means for data take-off from each axis, and provide for mounting electronic equipment behind the antenna assembly.

The antenna pedestal assembly consists of a stationary base azimuth- and elevation-rotating assemblies, and the antenna assembly. The stationary base provides for levelling. The azimuth rotating assembly mounted on the stationary base provides trunnion supports for

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the elevation rotating assembly which supports the microwave optics.

Natural Frequencies

The natural frequencies of a system can be defined as those frequencies where the system tends to oscillate or vibrate when acted on by some external force.

To determine the significant frequencies consider the system as two lumped masses with a connecting spring. A force applied to one mass results in two resonant frequencies: the locked-rotor resonant frequency and the free-free resonant frequency. The locked-rotor frequency is one at which the amplitude of motion at the system input is minimum. The motion at the output does not reflect this decrease in amplitude. At the free-free frequency, however, there is a peaking of the amplitude of motion both at the input and the output of the spring-mass system. It is noted that the free-free frequency is always larger than the locked-rotor frequency. Also, at both frequencies, the decrease in amplitude at the locked-rotor frequency or the increase at the free-free frequency is dependent upon the amount of damping in the system.

These frequencies are discussed here since they are very important considerations in designing an antenna pedestal assembly and drive system. There are many other resonance frequencies for the structure, but they are higher and usually do not affect system performance.

Pointing Accuracy

The pointing accuracy for the antenna system may be defined as the angular difference between the direction of propagation of the electro-magnetic wave at the maximum RF power density in the vicinity of the satellite and the angular direction indicated by the position-data output shafts. Pointing accuracy for the antenna and pedestal assembly only may be defined as the peak, mechanical angular-error summation for the azimuth and elevation axes from the theoretical RF beam axis to the output shaft on each

axis to which the shaft-position sensors are attached.

A pointing accuracy of 0.17° for the antenna and pedestal assembly per axis was achieved, limited by practical limitations in manufacturing, assembly, erection and measurement accuracies. These limitations in accuracies or errors can be divided into bias or DC errors and random errors. Bias errors such as azimuth and/or elevation axis inclination and feed-horn deflection due to gravity are constant and may be programmed out. Random errors such as effects of wind and/or solar radiation are not constant and cannot be programmed out.

The antenna is driven in azimuth by two 5-hp servo motors counter-torqued to eliminate backlash in the gear trains; the antenna is driven in elevation by one 5-hp servo motor. Backlash was eliminated by providing sufficient unbalance about the elevation axis on the counterweight side so that the teeth of the drive pinion were always in contact with those of the elevation bull gear.

The parabolic reflector is 85 feet in diameter and has a focal length-to-diameter ratio of 0.42. The reflector surface consists of solid, adjustable, aluminum panels. Electrical continuity is provided mechanically along all edges inside the reflector periphery. During erection of the antenna, the reflector was measured, using optical techniques, at 0, 45, 90 (zenith) and 180 degrees in elevation. A computer program was written expressly for the measurement and analysis of data; a best-fit parabola of 0.37-inch RMS was attained.

The hyperbolic reflector is 8.5 feet in diameter, has an RMS surface accuracy of 0.012 in., and is supported by a quadrupod.

This hyperbolic reflector can be positioned axially by remote control of a motorized drive mechanism, and laterally, vertically and angularly by manual means. The surface of the reflector was measured mechanically; those parameters necessary to define its surface were varied within certain limits; and another

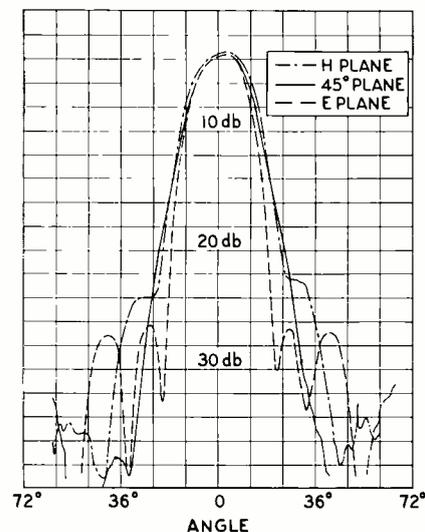


Fig. 2—Measured source pattern at 4.1 GHz.

computer program was employed to determine the best-fit hyperbolic surface.

The quadrupod was designed to reduce blockage under transmitting and receiving conditions and limit relative translational and rotational movement of the hyperboloid relative to the paraboloid. The feed cone was designed to house the feed system, two parametric amplifiers, tracking downconverters and front ends, stable local oscillators, noise measuring equipment and other test instruments.

Electrical energy was made available to the rotating portions of the antenna pedestal assembly from the stationary base by means of a maypole-type cable windup device. Cables were designed and fabricated to withstand torsion as well as bending stresses. From the azimuth to the elevation rotating structure, electrical cables were supported on cylindrical sections mounted at the elevation axis to accommodate an elevation rotation of 180 degrees.

The parametric amplifier mounted in the antenna assembly required cooling to 4.2 degrees Kelvin. This was accomplished through the use of a state-of-the-art closed-cycle cryogenic (helium) system. To provide sufficient on-the-air time for the earth station, two closed-cycle systems were installed in parallel and provided with automatic switchover from one to the other in case of malfunction. These were installed on the azimuth rotating platform.

A data take-off device is attached to each axis of the antenna pedestal through a bellows-type flexible coupling. The mechanical characteristics of the antenna pedestal are summarized in Table III. The antenna pedestal was designed for a six-weeks duty cycle as follows:

5 weeks:

The entire system to be 'on the air' 24 Hours/Day (regardless of standby time).
 Hours/Day 24
 Days/Week 7
 Targets/Day 24

TABLE III—Antenna Pedestal Characteristics

Characteristics	Azimuth	Elevation
Number of DC Servo motors	2	1
Rotational travel (degrees)	+300 and -300	-2 to +182
Velocity (max) Θ /sec.	0 to 3	0 to 3
Acceleration (max) Θ /sec. ²	0 to 3	0 to 3
Locked rotor frequency (Hz)	2	2
Max. breakaway friction (ft.lbf)	20,000	14,000
Max. running friction (ft.lbf)	16,000	11,200
Weight of pedestal (lb)	590,000	
Weight on azimuth bearings (lbs)	500,000	
Elevation load inertia referred to elevation axis and excluding gear train (slug-ft ²)	2,000,000	
Azimuth load inertia, referred to azimuth axis and excluding gear trains (slug-ft ²)	2,000,000	

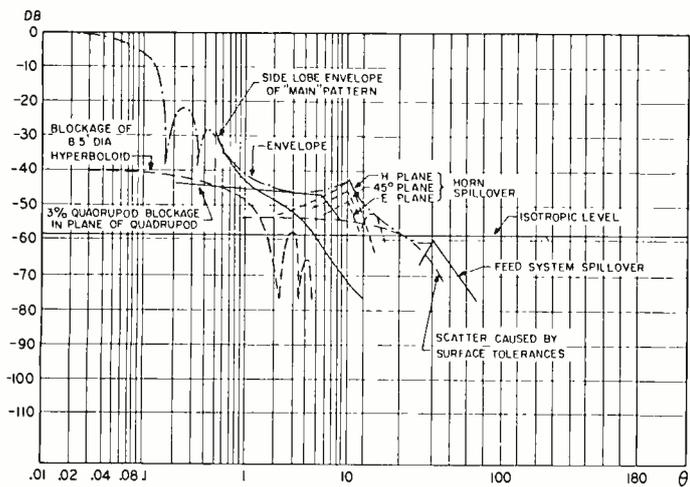


Fig. 3a—Antenna system pattern calculated from the source pattern at 4.1 GHz.

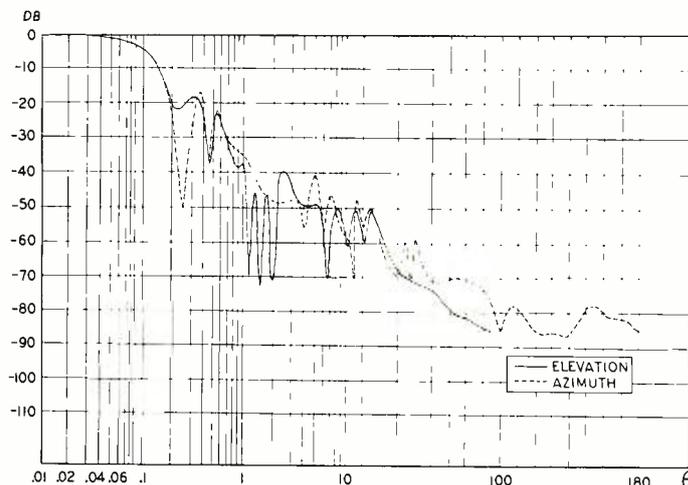


Fig. 3b—Directly measured antenna system pattern at 4.1 GHz.

Minutes/Target	40
Programmed steering (acquisition) ...	1 min.
Automatic tracking (after acquisition) ..	35 min.
	(minimum)
Return slew (180°)	4 min.
Standby (after each target)	20 min.

1 week:

Standby of the entire system with complete shutdown permissible not to exceed 1 week/yr plus 4 hrs/mo for planned maintenance.

The reliability required was 97% minimum; the downtime for the antenna pedestal was not to exceed 3% or 262 hours of any given one year period during the ten year life span. The downtime was to include all planned maintenance time.

RADOME DESIGN

Electrical Considerations

If cost considerations are discarded, heated radome-protected systems have better performance characteristics than exposed systems, with the exception of heavy rain conditions. The most obvious advantage of the radome-protected system is the elimination of wind fading.

On the other hand, radome-protected systems require special attention for the following cases:

- 1) Attenuation and reflection caused by the radome under ideal weather conditions,
- 2) Pointing and tracking inaccuracies associated with radome inhomogeneity,
- 3) Attenuation and reflection caused by precipitation,
- 4) Temperature stratification around the antenna, caused by the presence of the closed environment, and
- 5) Maintenance required for the skin of the radome.

Radomes can be divided into self-supported and air-supported categories. Although the self-supported types (space frame, rigid-dielectric) have better reliability and less maintenance requirements, they also have larger attenuation and scattering and higher investment cost. To reduce dry-weather noise temperature contribution, and inflated type of radome was selected. For the given

environment and antenna size, a 0.056-inch wall thickness, and a dielectric constant of maximum 3.5, resulted in minimum reflection coefficient and dry-weather noise temperature, with a flexible-membrane dacron fabric. The water-film formation for heavy-rain conditions was minimized by a hypalon coating, which, at least for a number of years, has reasonable, although not ideal, non-watering characteristics.

The pointing and tracking errors were minimized by uniformity of the radome fabric and minimizing the overlap at joints. No effect on this account was measurable on the completed system.

Mechanical Considerations

The air-supported hypalon-coated dacron radome is approximately spherical in shape and has a diameter at its equator of 120 feet. The height from the 90-foot base diameter to the pinnacle is 102 feet. The radome is attached and sealed by means of a steel base ring atop a circular concrete structure, which is actually part of the antenna pedestal building.

Air is ducted to the radome from a weather protected circular opening approximately 600 feet from the center of the radome. This air is supplied to the radome at pressure levels of 1.5, 3.0 and 5.5 inches of water, depending upon external wind conditions. Two anemometers mounted atop a 30-foot mast control the operating pressure level automatically with a time delay in the control system to minimize cycling under gust conditions. The radome was designed to withstand steady winds of 65 mi/h and gusts of 105 mi/h and to deflect less than one foot in any direction.

The three-foot diameter pinnacle of the radome incorporates aircraft warning lights, a lightning arrestor, a pneumatically operated air exhaust, an exit hatch to the outside of the radome, a 4,000 pound capacity sky-hook, and a

folding ladder. Heavy-duty copper cables are mounted on six-inch stand-offs from the lightning arrestor downward along the radome wall to a grounding installation. Thermocouples are attached to several points inside the radome to detect temperatures at various elevations.

The circular building on which the radome is mounted incorporates one 14-foot high by 14-foot wide by 55-foot long vehicle airlock and two personnel airlocks.

Multiple pressurization equipment, including self contained power units independent of the station power, are provided to assure fail-safe operation.

CONCLUSIONS

Canada's Mill Village earth station was probably the last of the large stations built for the purpose of experimental microwave communication. In fact, the station is presently used for mostly commercial satellite communication on a time-shared basis with COMSAT's Andover facility.

The system met all the original design objectives, and its communication performance in the bottom slot is characterized by an NPR (noise-power ratio) of about 35dB, with a conventional receiver for 240 voice channels, while working with the Early Bird satellite. This performance approaches the NPR characteristics of other stations with similar antenna aperture, but equipped with an FM feedback receiver.

The G/T_r ratio of the antenna exceeded by approximately 1dB the original design objective. Although the station has been in operation for only about 1½ years, it is already obvious that the antenna-radome complex is its most reliable subsystem, and probably its most important single feature; no downtime ever was reported on the account of the antenna system during this period of operation.

COST CONSIDERATIONS IN DESIGNING EARTH STATIONS

The cost of early ground stations varied considerably—partly because of their experimental nature and partly because substantial developmental efforts were included in their construction. The construction of ground stations is now entering a more mature phase: requirements are more precisely defined and standardized; characteristics of the available equipment and techniques are better known; and future technological developments, both in the spacecraft and in the ground terminals, are more closely anticipated as a consequence of the accumulated studies. Also, data for statistical variables caused by satellite behavior, weather, and site characteristics is beginning to accumulate. All these developments now make it possible to design a ground station more on a technical-business basis than during the era of experimental ground stations.

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ALTHOUGH a satellite communication ground station is quite complex, the main performance requirements can be summarized briefly (Table I).

TABLE I—Main Requirements for Satellite Communication Ground Stations

G/T_s : 40.7dB (400 MHz, $\theta = 5^\circ$ elevation angle, clear weather)
ERP: 95dBW (HS-303A)
ERP: 89dBW (Global System)
Receive Frequency: 3700 to 4200 MHz
Transmit Frequency: 5925 to 6425 MHz
No. of RF carriers: 1-20
No. of channels: 1-600 voice or 1 TV per carrier
Quality of channels: CCIR standards
Time of full operation capability: 99.7%
Down time: 0.1%
Tracking range: Full hemisphere
Polarization: circular or orientable linear

G = gain of the antenna
 T_s = noise temperature of the system

Within the limits specified in Table I, the designer still has considerable freedom in determining his station. Will he provide the full frequency band initially, when only part of this band is required for early operation? Will he meet the G/T_s requirement at 5° or at 1° or 2° higher? Should he select a large transmitter on the ground, or a smaller one rotated with the antenna? Should the down-time budget be utilized to take care of weather effects only, or be utilized for less reliable equipment? Should the tracking be based on either program steering, or autotrack, or both?

The selection of the *features* of the station will affect not only the cost effectiveness but also some other characteristics sought by the customers, such as flexibility, easy operation, maintenance, and low rate of obsolescence. Table II

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summarizes the features selected in the present study. The indicated choices are only the most important ones, and the selection is indicated by italics.

COST SENSITIVE SYSTEM PARAMETERS

The total cost of a ground station for a given set of requirements is determined by a very large number of system param-

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TABLE II—Main Features of the Ground Station

Compliance with requirements:	Full	Partial
Redundancy:	Full	Gracefully failing
Investment cost:	Rigid	Flexible
Operation method:	Centralized	Decentralized
Operation cost:	Low	Medium
System concept:	Fully developed	Partially developed with growth capacity
Subsystem concept:	State of art	Well proven
Component concept:	Modular, solid state	
Delivery:	12 months	14 months

eters. Fortunately, only a relatively small number of these parameters have substantial effect on cost and (or) are related to each other. When a subsystem parameter is independent of the rest of the system parameters, it can be optimized by itself, and will not enter into the overall studies.

The sensitive system parameters are:

- 1) Use of radome;
- 2) Diameter (D) of paraboloid reflector.
- 3) RMS surface accuracy (Δ) of paraboloid for ideal weather;
- 4) Lock-rotor frequency f_L of antenna structure;
- 5) Weight W_s of subreflector support (a Cassegrain antenna is assumed);
- 6) Diameter (d) of hyperboloid reflector;
- 7) Aperture size (a) of feed horn;
- 8) Average antenna efficiency, $\eta_{AV} = 0.5 (\eta_{Rx} + \eta_{Tx})$;
- 9) receive-to-transmit antenna efficiency ratio ($\tau = \eta_{Rx}/\eta_{Tx}$);
- 10) Tracking accuracy (δ) of antenna;
- 11) Noise temperature (T_{Rx1}) of main parametric amplifier;
- 12) Down time (R_{Rx1}) of main parametric amplifier;
- 13) Noise temperature (T_{Rx1}) of back-up parametric amplifier;
- 14) Down time (R_{Rx1}) of back-up parametric amplifier;
- 15) Output power (P_{Tx1}) of main transmitter;

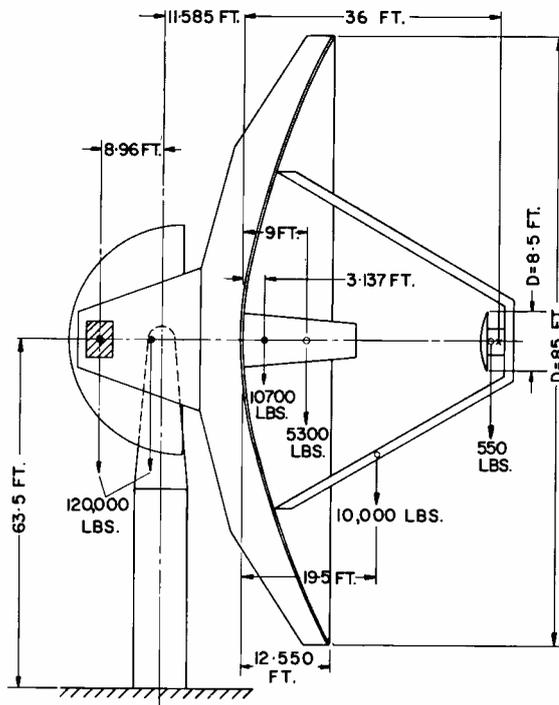


Fig. 1—Mechanical layout of a typical 85-ft diameter antenna.

- 16) Down time (R_{Tx1}) of main transmitter;
- 17) Output power (P_{Tx2}) of back-up transmitter;
- 18) Down time (R_{Tx2}) of back-up transmitter;
- 19) Down time (R_{As}) of antenna for synchronous satellite;
- 20) Down time (R_{Am}) of antenna for medium orbit satellite;
- 21) Threshold extension (L);
- 22) Distance between antennas (K_A) when more than one antennas is used; and
- 23) Distance between first antenna and control building (K_C).

These parameters depend on at least one parameter in the set; the value for each must be determined by varying all the other parameters which have influence, and also by varying those requirements which are not constant (Table I). A computer program can then be used to determine the minimum of the total cost function.

UPLINK AND DOWNLINK FADING WITH AND WITHOUT RADOME

Two possible cases are of interest:

- 1) The customer prefers to use a radome because of its operational advantages. In this case, there is no choice. Nevertheless, the fading characteristics must be known, to obtain the most economical system.
- 2) The customer wants a system with the highest possible cost effectiveness. In this case, the choice between radome and no radome is open; for most sites, the systems without radomes are more economical.

Generally, weather causes a G/T_s fading in the receive frequency band and an ERP (effective radiated power) fading in the transmit frequency band. The G/T_s fading is usually more important, since it

is more costly to compensate for. This fading may be caused by rain, wind, snow, ice, and solar radiation (differential temperature).

The greatest fading shows up for the smallest antenna size, lowest receiver noise temperature, and highest elevation angle; also fading is greater in the radome-protected system. For a given G/T_s ratio, the fading decreases with increasing antenna size (a little less rapidly for systems with radome than for systems without, but the absolute value of signal fade is less for the system with no radome).

In the fading calculations of the system without radome, it was assumed that the total time per year when the ice on the antenna is more than 1.5 inches thick, or the snow is more than 5 inches deep, is restricted to 8 hours. For stations with two antennas, this would not present

a serious problem, particularly if the other (standby) antenna is under a radome. For stations with one antenna, the care of medium orbit satellites does not present a problem, since system interruptions for satellite changeover already exceed 8 hours. For stations with a single antenna and a synchronous satellite (a more practical case) virtually no interruption is tolerated.

Assuming that the paraboloid has F/D of 0.42, the lower edge of the reflector is approximately horizontal for elevation angles of 30° and is the most sensitive for snow accumulation. However, the total area of the reflector where the tangent to the surface encloses less than 45° with the horizontal, is less than 831 ft^2 , when the aperture area is 6318 ft^2 . For most practical cases, snow accumulation for angles above 45° is negligible. Then the snow or ice removal from the 831 ft^2 surface, by electrical heating, is quite inexpensive. For instance, when the snowfall rate is 2 in/h, and the density factor is 0.1, then the total melting power is 9.9 cal/sec (41 W/ft^2).

The efficiency with which this melting power can be provided depends on thermal radiation losses, distribution of heating elements, wind velocity, etc. For ideal heat distribution and no wind, the efficiency is about 80%, which drops to 66% for 20 mi/h wind. Assuming 41% efficiency, the heating power requirement is 100 W/ft^2 . Such a heater can be provided for a cost of approximately 10 to 20\$/ ft^2 . This is a fraction of the cost of a radome installation.

Another weather hazard is icing at temperatures between 26 and 32°F and high relative humidity. For most sites, the icing rate very rarely exceeds 0.1 in/h for prolonged periods. Therefore, 50 W/ft heating power is adequate for this purpose. If the heating facilities for de-icing are restricted for the inner part of the reflector, defined by level lines within which half of the total RF power is

TABLE III—Mechanical Data of a Typical 85-ft Diameter Antenna

Component	Weight (10^3 lbs.)	Distance from pivot (ft)	Moment (10^3 ft. lbf)	Reflector area (ft^2)	Weight/Area (lbs/ ft^2)
Feed Cone	5.3	20.58	109.074		
Quadrupod	10.0	31.08	310.080		
Hyp.	0.55	46.58	25.619		
Basic panels	10.7	15.76	168.632	6140	1.74
Extra panels	—	—	—	—	—
Basic trusses	54.3	13.0	705.9	6140	8.84
Extra trusses	—	—	—	—	—
Subtotal			1319.305		10.58
Shell	120.000	-1.97	-60.695		
Counterweight	120 000	-10.48	-1258.610		
El. structure	320,850				
Az. structure	212.150				
Ant. structure	533.000				
Cost (\$)	740,000				
\$/lb	1.39				

NOTES:
 $D = 85 \text{ ft.}$
 $\Delta = 0.037 \text{ in. RMS}$
 $f_s = 2.25 \text{ Hz}$
 Hyp. Support: Steel Quadrupod

TABLE IV—Calculated Lock Rotor Frequencies for Various Practical Cases

D(ft)	d	lgd.	d ^{1.0}	d ^{0.7}	d ^{0.1}	f _L								
						Case	1		2		3		4	
						kHz	2.47	1.6	2.47	2.47	2.25	2.14	1.91	2.14
85	1	0				2.47	2.35	2.10	2.47	2.47	2.25	2.14	1.91	
90	1.0588	.02472	1.0953	1.0407	1.0055	2.25	2.14	1.91	2.37	2.45	2.23	2.12	1.89	
95	1.1176	.04828	1.1945	1.0810	1.0110	2.06	1.97	1.75	2.28	2.44	2.22	2.11	1.88	
100	1.1764	.07056	1.2967	1.1205	1.0163	1.90	1.81	1.62	2.20	2.43	2.21	2.10	1.87	

concentrated, then an additional 26% of the paraboloid reflector (in the upper half) has to be equipped with (half-density) heaters.

The operational cost of such a heater facility is only a fraction of the operational cost of the radome. This example is typical of problems related to weather protection of large antennas without radomes.

ANTENNA SYSTEM COST CONSIDERATIONS

Before any cost analysis of the system can be made, the cost of the antenna system must be determined as a function of its diameter, surface accuracy, lock-rotor frequency, tracking accuracy, and design of the subreflector support. The situation can be analysed on a typical existing 85-ft. diameter design; Fig. 1 shows the basic layout of the antenna. The breakdown of the weight and overturning moments are indicated in Table III.

One of the factors influencing the cost of the antenna is the type of support for the subreflector. Fig. 2 indicates the relative cost variation of the above antenna with a monopod support in an open environment for no-wind conditions. Three different design conditions were assumed for the accuracy of the reflector:

Case 1: Practical design, in which the surface accuracy, Δ, varies according to the curve given in Fig. 2, as the diameter varies. This surface accuracy variation is obtained without a reinforcement of the back-up structure. The "practicality" in this design means that only the counterweight, hyperboloid support, and surface panels beyond the 85-ft. diameter, are changed relative to Table III. The limit for this design is about 95 ft.

Case 2: "Ideal" design, with varying Δ. This case is similar to case 1, but the structure is redesigned to compensate for varying weight conditions. Below 95.5 ft., the structure is lighter; above that limit it is heavier than the "practical" design.

Case 3: Ideal design with constant Δ. The selected values are: 37, 40 and 50 τ).

In each case calm weather was assumed. Fig. 3 shows the relative variation of cost of an inflated radome versus antenna diameter, if this protection is added to the system.

From Table IV, it can be seen that the monopod results in a superior lock-rotor frequency. Generally, the lock-rotor frequency decreases with the diameter, because of the increase of the structural

weight, but with a light hyperboloid support the lock-rotor frequency can be kept above 1.8 Hz. This frequency is adequate for tracking medium altitude and synchronous satellites.

MINIMUM COST FOR A GIVEN G/T_s RATIO

The two most important components in the cost, to obtain a given G/T_s ratio, are the antenna structure and the low-noise preamplifier.

Assuming 500-MHz receiver bandwidth, the parametric amplifiers are the most practical preamplifiers to achieve low noise temperatures. Generally, the cost of a parametric amplifier increases rapidly by decreasing noise temperatures; the necessary cooling machine becomes more complex, less reliable, and more expensive to maintain. There are at least four different types of amplifiers for the various temperature ranges. Their characteristics and price range are exhibited in Fig. 4.

The indicated cost figures refer to the currently required small quantities. A cost improvement of an order of two is expected in the coming five years as larger quantities of standardized types of these amplifiers will be required. The basic character of the curve on Fig. 4, however, is not expected to change during the next 5 year period.

Using Figs. 2, 3, and 4, the cost variation of the antenna structure, plus parametric amplifiers, versus antenna diameter can be calculated (Fig. 5). The same figure indicates the variation of G/T_s and lock rotor frequency.

Fig. 6 indicates the cost of the structure plus parametric amplifiers for constant G/T_s ratios. It can be seen that for each G/T_s ratio, there is an antenna diameter and receiver noise temperature, which results in minimum cost. With increasing G/T_s requirement, this minimum shifts toward larger antennas and smaller noise temperatures. For the range of 40.7dB < G/T_s < 42.7dB, the optimum antenna diameter is 91.5 ft. < D < 99.5 ft., and the receiver temperature is 45°K > T_{rx1} > 22°K. The "optimum" receiver noise temperature falls within the range of helium gas type cooling machines.

On the basis of previous results, it is possible to predict the cost of a given increase of the G/T_s ratio under optimum conditions. The approximate differential increases in cost needed to obtain 1dB improvement in G/T_s, are indicated in Table V.

TABLE V—Cost of 1-dB G/T_s Increase for Optimum Conditions (Rohr dish, aluminum quadropod)

Increase from	to	Cost (10 ²⁸)
40dB	41dB	38
41dB	42dB	74
42dB	43dB	139
Ave.		84

DETERMINATION OF OPTIMUM FEED SYSTEM

Excluding the possibility of focal-point feeds as operationally inconvenient, and horn reflectors as costly, the only remaining type of feeds is the Cassegrainian. In this category, three main types of feeds are developed, with increasingly better characteristics. These are:

- 1) One horn, single-mode feeds;
- 2) One horn multimode feeds; and
- 3) Multihorn multimode feeds.

The most important single characteristic related to the feed is the overall average antenna efficiency η_{AV} = 0.5 (η_R + η_{Tx}), where η_R and η_{Tx} are the average antenna efficiencies for the receive and transmit band respectively. Fig. 6 shows the cost of these feeds versus their antenna efficiency. The generalized curve between these discrete points is somewhat academic, but it predicts the general tendency for the cost of antenna efficiency. Using the previous results, the differential cost variations versus η_{AV} can be calculated. Fig. 7 shows the change of cost for the 100-ft dish, aluminum quadropod, and T_{rx1} = T_{rx2} = 22°K. The curve predicts, for this case, an optimum value of -2.80dB for η_{AV}. The closest existing feed system is the 1-horn multimode feed, with 2.64dB.

COST OF THE EFFECTIVE RADIATED POWER

For the requirements given in Table I, the cost of the effective radiated power is determined by the antenna gain (diameter of antenna), the reliability of the transmitter system, and the location of power amplifiers relative to the feed.

Fig. 8 shows the variation of cost for antenna diameter, D = 105 ft. and for ground located transmitters, assuming 2.5-dB transmission line loss between the transmitter tube output flange and the antenna feed input flange. The cost of transmitted power was calculated for the condition that output power of the tube is sufficiently below saturation, to keep third order products below -20dB

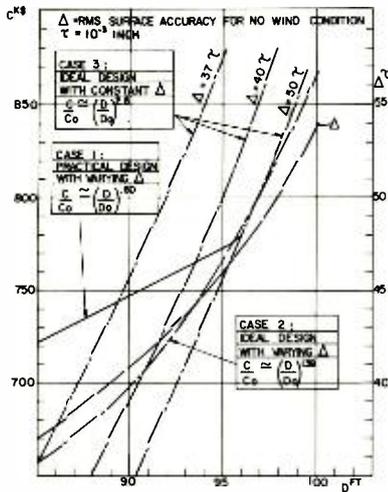


Fig. 2—Cost and RMS surface accuracy of antenna structure versus diameter (with monopod support).

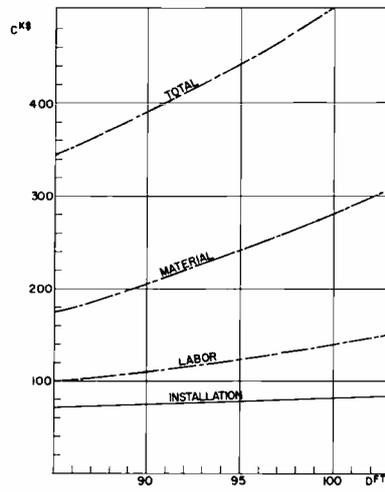


Fig. 3—Cost of inflated type radome versus antenna diameter.

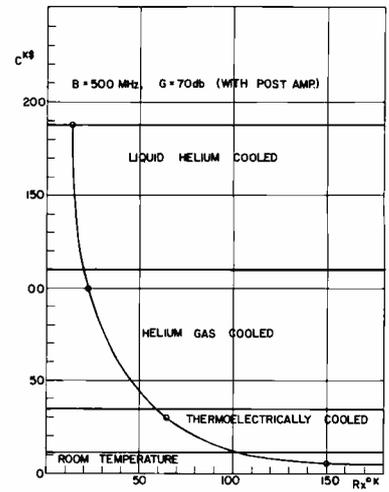


Fig. 4—Cost of parametric amplifier versus receiver noise temp. (instantaneous bandwidth: 3.7 to 4.2 GHz, post amp. included).

for 2-carrier operation. Two types of transmitters were assumed:

- 1) "Modular" type of transmitter, in which 1.88kW, 3.53kW, and 6.63kW useful power can be obtained by the paralleling of two, four, and eight 1kW tube modules, respectively, with a combination efficiency of 94% (such a 1kW tube is not available at the moment).
- 2) Single tube approach for the 1kW, 2.8kW (Siemens), 5kW (Hughes) case

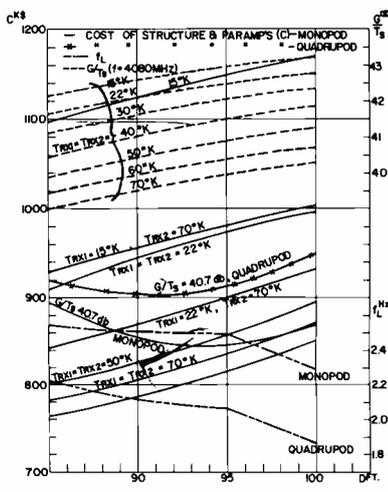
Fig. 8 shows that the cost of transmitter power increases more than linearly with the level of the required ERP and the variation increases by decreasing the antenna diameter.

OPTIMUM ANTENNA EFFICIENCY RATIO FOR THE RECEIVER AND TRANSMITTER BAND

From the cost variation of G/T_s and cost of ERP (Fig. 8) the optimum value of the $\tau = \eta_{Rx}/\eta_{Tx}$ ratio can be calculated.

Fig. 9 indicates the differential cost

Fig. 5—Cost, G/T_s and f_L versus antenna diameter ($\theta = 5^\circ$, $T_A = 36^\circ K$)



variation as a function of τ for ERP = 95dBW, $D = 100$ ft., and $\eta_{AV} = -2.65$ dB. (1-horn multimode feed).

COST OF THRESHOLD EXTENSION

To provide adequate fading margin in the receiving system, at an economical cost, the threshold level of the demodulator must be extended relative to the level (10dB) achievable by a standard FM demodulator. Various methods have been recommended for this purpose (FM feedback, phase lock, IF bandwidth reduction), which, however, have one common characteristic: the cost of such a demodulator increases with the number of required RF carriers, with voice channel capacity, and with the required threshold improvement (ΔL).

Fig. 10 shows the variation of cost for 1-dB threshold improvement versus the number of voice channels (n) for the number of RF carriers of $N = 2, 6, 10$

Fig. 6—Cost of feed system versus average antenna efficiency.

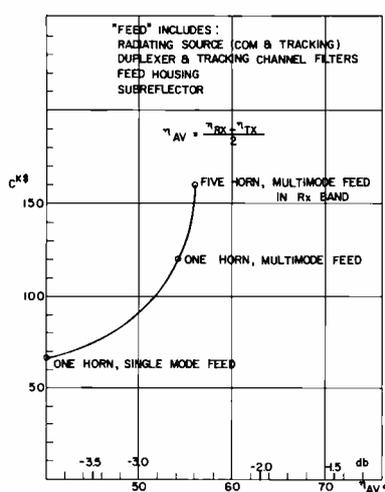
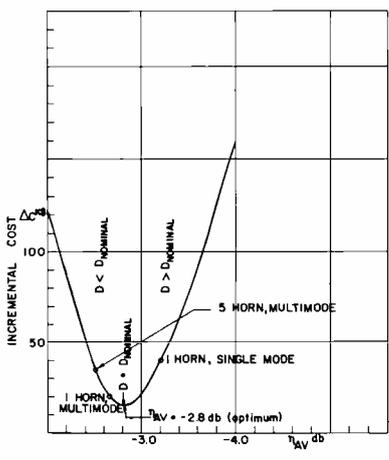


Fig. 7—Incremental cost variation of antenna structure and feed versus η_{AV} for $T_{RX1} = T_{RX2} = 22^\circ K$ and D (nominal) = 100 ft.



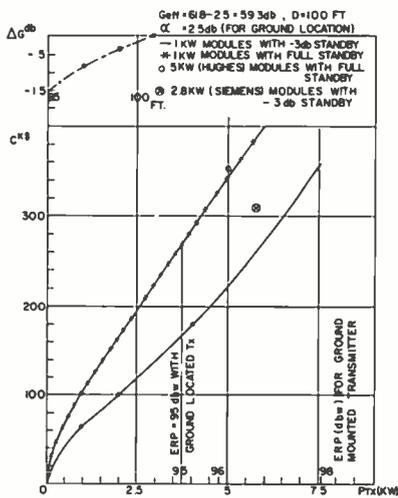


Fig. 8—Cost of transmitter power.

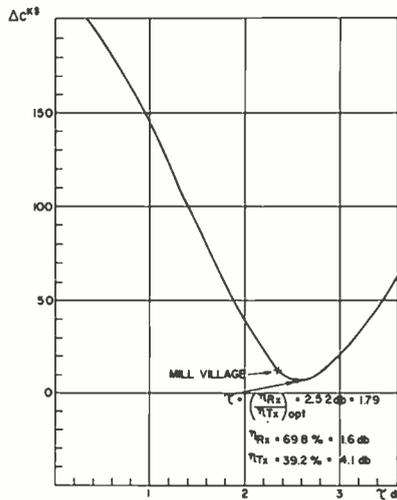


Fig. 9—Differential cost variation of antenna structure paramps and transmitter versus $\tau = \eta_{Rx}/\eta_{Tx}$ (ERP = 95 dBw, D = 100 ft, $\eta_{AV} = 54.59\%$)

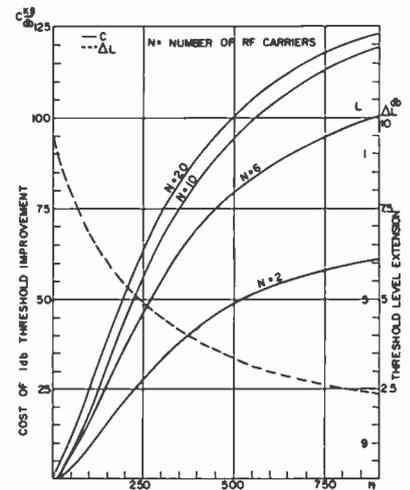


Fig. 10—Cost of FM threshold improvement and maximum possible improvement versus number of voice channel, γ .

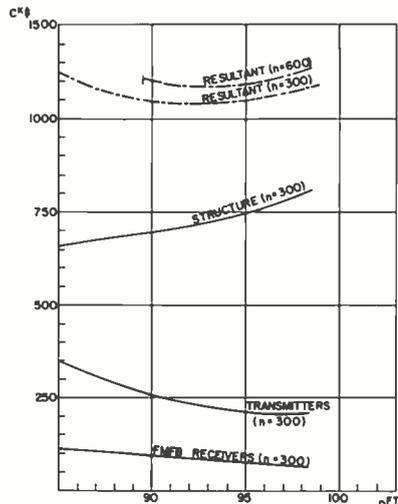
To illustrate the sensitivity of the system cost to the cost of the antenna structure, cost of power amplifier, and cost of FMFB receiver, the variation of the cost of these equipments versus antenna diameter is plotted in Fig. 11. The conditions for this figure are indicated in Table VI.

TABLE VI—Typical Conditions for a Practical RF System

$T_{Rx_1} = 22^\circ K$
$T_{Rx_2} = 60^\circ K$
$P_{Tx_1} = 95dBm$ (in more than 90% of time)
$P_{Tx_2} = 92dBm$ (in more than 10% of time)
$N = 2$
$n = 300$ and 600
Hyperboloid support: Monopod
No radome
$\theta = 5^\circ$

It can be seen from Fig. 11 that by ideal (proportional) design of the three subsystems which influence the selection

Fig. 11—Cost of antenna structure, transmitters, and FMFB versus antenna diameter for $n = 300$ and 600 .



of antenna diameter, the total cost can be minimized around $D = 93.5$ ft.

By the use of the curves given previously, a series of cost tables can now be prepared for various combinations of the parameters in Table VI. These combinations have to be restricted to an acceptable standard of reliability (down time) consistent with the 99.7% overall operational reliability specified in Table I.

CALCULATION OF COST FOR OPTIMUM CONFIGURATIONS

Fig. 12 indicates the variation of the approximate cost of a voice channel (C) as a function of the total voice-channel capacity V of the station. It can be seen that for the small user ($V = 48$ channels), the cost per channel is very large (minimum \$60,541). Nevertheless, this cost may still be attractive, if there is no other way for reliable communication. For the medium user ($V = 240$ channels), the installation cost per channel is very economical (\$11,681, minimum, with feed cone mounted transmitter, without reflector heater, and with two simultaneous carriers). Finally, for a very large user ($V = 1200$), the cheapest system costs \$2606/channel. A more refined system (with program steering included), costs \$2741/channel, and a deluxe version (with radome), \$3100/channel.

CONCLUSIONS

On the basis of the previous analysis, the following conclusions can be made:

- 1) With the exception of very severe climatic conditions, the use of radome is not economical for commercial satellite communications. For identical performance, a system with radome cost about 13.5% more than a system with antenna heaters.
- 2) The limit of the present antenna designs can be expanded to 100-ft. diameter.

- 3) A pre-stressed steel hyperboloid support (monopod) offers a 0.2dB improvement in the G/T , ratio, and an associated saving in the structure. Hyperboloid positioning mechanism virtually disappears in this structure.
- 4) For channel capacities/carrier of 300, or more, the optimum antenna diameter is above 90 ft. To provide future growth and room for lower cost receiver front ends, an antenna diameter of 95 ft. should be selected.
- 5) The optimum type of feed system is the single horn, multimode design. The system economy does not tolerate either a simpler or a more complicated feed concept.
- 6) The optimum ratio for the receive-to-transmit frequency-band antenna efficiency is 2.52dB.
- 7) A modular type of transmitter is required to make an optimally adaptable system to the various requirements. For this purpose, the development of a rwr with 1400-W saturated output is necessary with an operational level of about 1000 to 1100W.
- 8) It is more economical to locate the transmitter in the feed cone than on the ground, but very high reliability must be achieved before customers will accept such a location.
- 9) The back-up transmitter can be -3dB, relative to the main transmitter, without affecting overall loop performance, if it is operated only in a maximum 10% of the time.
- 10) The main receiver front end has to be a helium-gas-cooled paramp for stations with 40.7-dB G/T , ratios.
- 11) The cost of FMFB receivers represents a very substantial part of the station for a large number of channels. The development of FMFB receivers, in which cost can be made proportional to the number of voice channels and required threshold improvement, could result in a substantial saving in the cost of the total station.
- 12) There is about one-million-dollar difference between the price of the cheapest and most expensive stations, among the analyzed cases.
- 13) The cost per channel varies between very wide limits (from about \$60,000 for a 48 channel equipment, to about \$3,000 for a 1200 channel equipment).

THE WIDEBAND COMMUNICATIONS SYSTEM OF CANADA'S MILL VILLAGE COMMUNICATIONS SATELLITE EARTH STATION

This paper describes the transmitting and the receiving equipment comprising the Wideband Communications facilities of Canada's communications-satellite Earth Station at Mill Village built for the Department of Transport by RCA Victor Company, Ltd. Various systems aspects, noise, interface requirements, and equipment locations are also discussed.

JOHN A. STOVMAN, Ldr.

RF Equipment

Aerospace Engineering

RCA Victor Company, Ltd.

Montreal, Canada

CANADA and the United States agreed in 1963 to participate in a space communications experiment using a proposed NASA satellite to be known as the Advanced Technological Satellite (ATS). General characteristics of this experimental space link for telephony signals would be SSB transmission in the up-path (ground to satellite), and FM transmission in the down-path (satellite to ground), while for television signals they would be FM for both up-path and down-path.

Canada's contribution to the experiment was the development, construction, and operation of a communications-satellite earth station in the eastern part of her territory, forming one terminal of the experimental system. Canada's Department of Transport was authorized to proceed with the station.

EARLY PLANNING BY RCA VICTOR, LTD.

RCA Victor Company, Ltd., in Montreal, Quebec, was engaged in a consulting capacity for the preparation of system parameters and specifications, and assistance in site selection. A contract was awarded for the project management, system engineering, integration, and

This work was done under Contract Number 73118, File No. 6801-663 Department of Transport, Ottawa, Ontario. Final manuscript received April 24, 1967.

contracting responsibilities for the antenna, radome, servo and tracking system, transmitters, receivers, and low-noise amplifier. The Department of Transport acted as the design authority and retained responsibility for building, services, multiplex, and boresight.

The location chosen for Canada's earth station was near Mill Village, Nova Scotia, some 9 miles from the Atlantic ocean. This site is relatively free from interference from radio relay systems and aircraft, and is reasonably close to a major communications terminal.

While the Mill Village station was under construction, the launch date for ATS was delayed due to the increasing diversity of the experiments.

Meanwhile, the Communications Satellite Corporation, (COMSAT) obtained permission to own and operate commercial satellites, placed the "Early Bird" satellite into orbit, and leased Andover (Maine) earth station for the American terminal of its operation. Attention focused on the possible use of Mill Village as a second North American commercial terminal sharing the duties with Andover. Expediency and time would not permit the construction of a second earth station for this purpose, therefore the experimental station would have to be used until it could be relieved by



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TABLE I—Initial Operating Frequency Capability for Mill Village

Satellite	Transmit Frequencies (MHz)		Receive Frequencies (MHz)		Beacon Frequencies (MHz)
	Telephony, TV Video	TV Audio	Telephony, TV Video	TV Audio	
ATS (NASA)	1) 6212.094	Subcarrier	4119.599	Subcarrier	4135.946
	2) 6301.050	Subcarrier	4178.591	Subcarrier	4195.172
Early Bird (ComSat)	1) * 6389.97	6400.97	4081.00	4092.00	4104.14
	2) ** 6301.02	6290.02	4160.75	4149.75	4137.86

* Used in North America

** Used in Europe

another Canadian station. The capability for handling signals through Early Bird were therefore added to Mill Village requirements while the station was under construction. Thus, Mill Village had a dual requirement from the outset, and this situation is reflected in many of the system design details and equipment complements.

BASIC STATION CONCEPT

Conceived with an experimental viewpoint, the communications capabilities of Mill Village were to be kept flexible. Primary services would be for Early Bird and ATS, as reflected in Table I. However, the earth station design, through the addition of relatively inexpensive and simple hardware, must be capable of operation at other frequencies. Requirements for the initial equipment complement were as follows:

- 1) Transmit and receive up to 1200 telephony channels with a performance meeting CCIR recommended standards;
- 2) Transmit and receive 525 line monochrome television signals with a performance meeting CCIR recommended standards;
- 3) Transmit both FM and SSB signals with powers up to 10 kilowatts average anywhere in the 5.925- to 6.425-GHz common-carrier band;
- 4) Receive two FM or PM carriers simultaneously, at power levels as low as -100 dBm anywhere in the 3.7- to 4.2-GHz common-carrier band;
- 5) Achieve a dry weather system noise temperature of 65°K at an antenna elevation angle of 7.5° above the horizon; and
- 6) Track any present or future satellite

TABLE II—System Thermal Noise-Temperature Budget (Antenna Elevation Angles 7½° Above Horizon)

Contributor	Noise Temp. (°K)
Atmosphere (dry weather)	17
Dry Radome (absorption and scattering)	9
Antenna Sidelobes	9
Feed System and Waveguide	17
Parametric Amplifier	13
Other Amplifiers	1
<i>Total System Temperature</i>	65

in an orbit appropriate for communications.

For convenience in the distribution of baseband signals throughout the station, the following baseband signal standards were selected:

telephony: -20 dBm test tone across 75 ohms, unbalanced;

video: 1 volt peak-to-peak, positive going, across 75 ohms unbalanced; and

audio: +9 dBm (maximum signal) across 600 ohms, balanced.

NOISE CONSIDERATIONS

Noise is a basic limitation in all systems. In communications systems, noise is generally classified into two types:

Thermal noise which is generally produced by the physical temperature of amplifiers and lossy elements such as waveguides, cables, etc;

Intermodulation noise which is produced after demodulation by non-linear circuit elements and uncorrectable group delays in transmission elements.

Most thermal noise originates in the signal processing stages of the receiving system, while intermodulation noise may result from deviations in the equipment parameters almost anywhere; however, the latter is usually more prominent in the frequency limiting circuitry such as filters, amplifiers, and the transmitter power tube.

Since the performance specifications for communications links are given as noise aggregates, more thermal noise can be tolerated for economic reasons than intermodulation noise. It is very

TABLE III—Design Objective for the Intermodulation Noise Budget (300 channel)

Contributor	Noise (picowatts)
FM Exciter	200
Receiver (FM Path)	330
Power Amplifier	80
Parametric Amplifier	50
Feed (4 GHz path)	25
Feed (6 GHz path)	25
Baseband Link	50
<i>Total Noise</i>	500
Equivalent Noise Power Ratio: 44.1 dB	

expensive to provide additional ERP capability in satellites. Thus, ¾ or more of the permissible 10,000 picowatts of psophometrically weighted noise allowed by the CCIR standards for telephony is usually allowed for the thermal-noise contribution; the balance is for intermodulation noise and is shared by both the satellite and earth-based equipment non-linearities.

Signal power radiated earthwards by present generation satellites is quite modest; at the earth station, the power received by the antenna in the order of -90 to -100 dBm. Since wide-index FM is the rule, power is spread out over a broad-signal spectrum. The useful recovery of these signals is a difficult task and requires special low-noise techniques and equipment.

To prevent thermal noise contributions from exceeding the allowance, system noise temperature must be kept below 65°K under dry weather conditions. Table II lists the contributors to the system noise temperature for the minimum antenna elevation angle of 7½° above the horizon. This very low system temperature was achieved by:

- 1) Reducing the antenna side-lobe pickup by careful design;
- 2) Reducing the feed system attenuation and mismatch losses to very low levels, and
- 3) Physically cooling the first RF amplifier in the receive path.

The first two of the above techniques are outside the scope of this discussion; the third is appropriate. The first RF amplifier, a parametric amplifier, was cooled to 4.2°K in a closed-cycle cryogenic refrigerator. A parametric amplifier, rather than a maser, was chosen because of its relative simplicity and its wide instantaneous bandwidth. When cold, the amplifier produced about 13°K of the measured 65°K noise temperature.

For intermodulation noise the design goal was set at 500 picowatts or less so that future requirements would not be compromised. Table III summarizes the designed upper level of performance of the station with respect to intermodulation noise contributions from the various sources of non-linearities.

EQUIPMENT LOCATIONS

The station consists of a central-control building and an antenna structure protected by a radome and separated from the control building by about 1200 feet. Thus the antenna beam clears the top of the control building when the antenna elevation angle is as low as 3° above the horizon. More antennas may be added to the complex as long as the spacing

between structures provides the necessary beam clearances; a total of six antenna structures could be accommodated and served by the one control building.

The antenna uses an 85-foot diameter reflector with a Cassegrainian feed system and is mounted on an AZ-EL type of pedestal mount. A feed cone located at the center of the reflector houses the low-noise amplifier and the receiver front ends. Below the reflector is a 19-foot diameter cage in which the transmitter RF assemblies are placed. The antenna system, antenna pedestal, antenna radome, reflectors, and feed systems are described in another paper.¹

The high-voltage transmitter power supplies are located on the radome floor at the base of the antenna; heat exchangers are located outside the radome structure. Adjacent to the radome, an equipment annex houses the main portions of the receiver, excitors, transmitter control, and parametric amplifier controls. Signal interface between the annex and the antenna-mounted equipment is at the IF frequency and passes through a "maypole" cable wrap through the azimuth axis and a cable "loop" past the elevation axis.

Baseband, multiplex, and test equipments are located at the control building. Therefore, baseband transmission links connect the control and radome buildings; telephony, television audio, and video signals are passed through the buildings in both transmit and receive directions.

COMMUNICATIONS SYSTEM

A block diagram of the communications system equipment is shown in Fig. 1. The components may be divided into 1) *transmitting* equipment, 2) *receiving* equipment, and 3) *baseband* equipment.

Transmitting Equipment

The transmitting equipment comprises 1) an SSB exciter, transmitter, heat exchanger, power supply; and 2) an FM exciter, transmitter, heat exchanger, power supply.

The use of SSB requires very tight control of absolute frequency: frequency shifts more than a few hertz are not tolerable, since considerable signal distortion will result from the loss of harmonic relationships between the frequency components.

Because the transmit frequencies are in the 6-GHz region, stabilities of the order of 1 part in 10^8 (long term) are necessary. Therefore all IF, RF, and reference frequencies are derived from a single, highly stable 5.0 MHz crystal

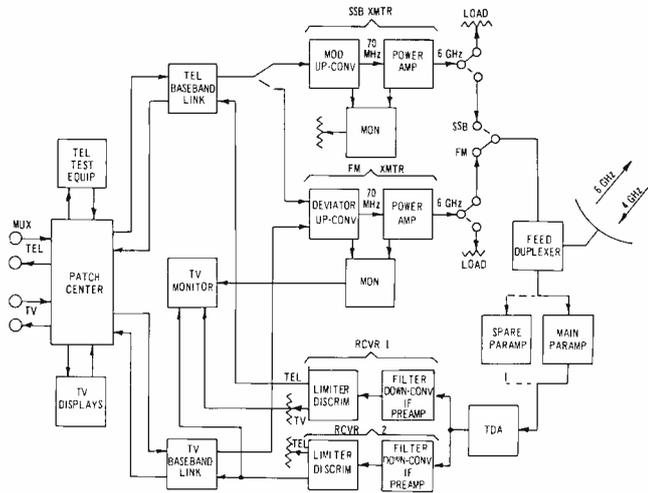


Fig. 1—Block diagram of the communication system of Mill Village.

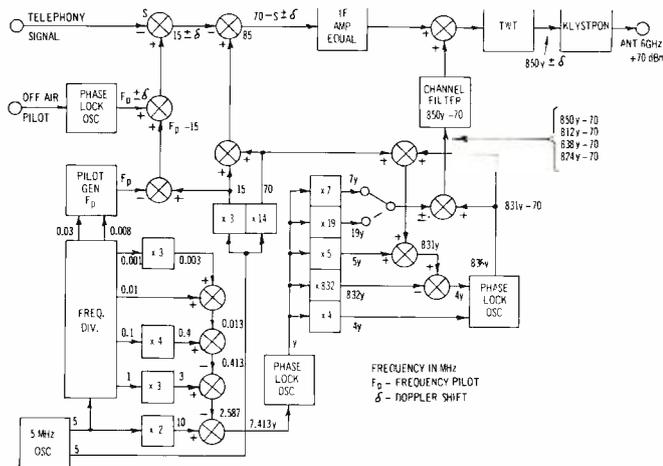


Fig. 2—Block diagram of the SSB transmitting system.

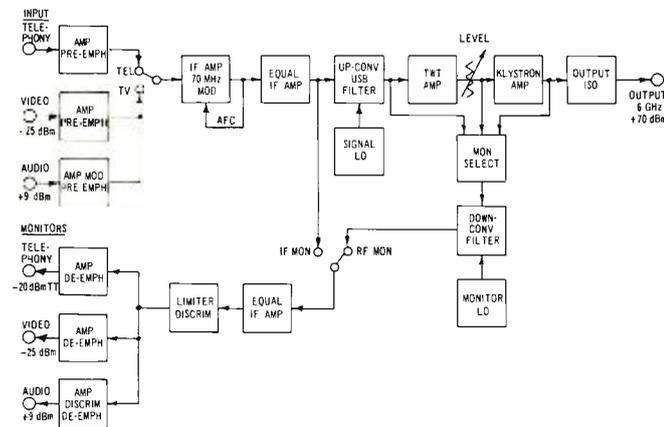


Fig. 3—Block diagram of the FM transmitting system.

oscillator. Fig. 2 is a block diagram of the SSB System.

The FM transmitting system is simpler in concept than the SSB since frequency amplitude correction feedback circuits are not required. However, FM must handle telephony and television, video and audio, therefore the flexibility and complexity of its baseband and its circuit parameter adjustments must be greater. Fig. 3 is a block diagram of the FM transmitting system; the waveguide transmission line has a switch permitting selection of either FM or SSB power as the radiating source.

Telephony and television video signals are handled conventionally. The audio signals may be handled in two ways: the subcarrier method, as adopted for the ATS, and a separate carrier method.

Receiving Equipment

Two separate RF signals may be simultaneously received. One signal may be the desired signal originated by another distant earth station while the second may be the "off-air" monitor for the station's own transmissions. To provide this capability, the following receiving equipment is used:

- 1) Two liquid helium cooled, two-stage parametric amplifier systems: a main wideband system and a standby narrowband system.
- 2) A two channel receiving system consisting of one low-noise two-stage room temperature tunnel diode amplifier followed by two sets of IF mixer-

Fig. 4—Block diagram of the parametric amplifier.

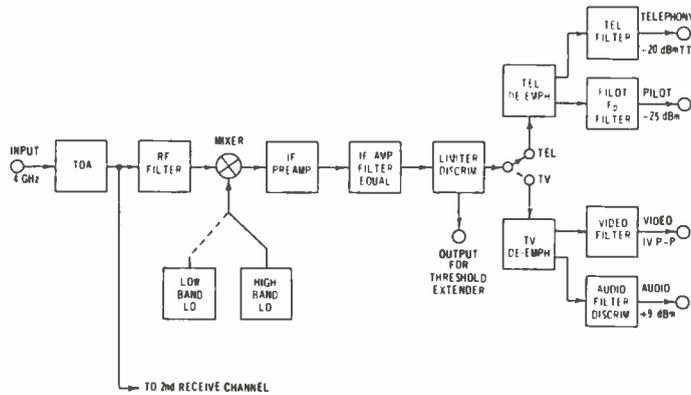
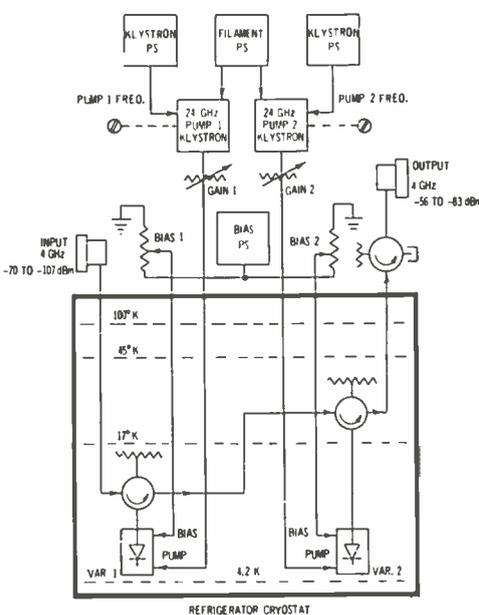


Fig. 5—Block diagram of a receiver system.

preamplifiers, IF main amplifiers, limiters, demodulators, and baseband amplifiers and de-emphasis circuits for telephony and television.

The parametric amplifiers, tunnel diode amplifier, and IF mixer preamplifiers are located in the feed cone to avoid the introduction of significant noise caused by waveguide losses. The remaining equipments are located in the annex. Fig. 4 is a block diagram of the parametric amplifier system; Fig. 5 is a block diagram of one channel of the receiver system.

Baseband System Equipment

The baseband system includes the transmission links between the buildings, and the monitoring equipment necessary for control and analysis of the signals being handled. Such activities begin in the control building and center around control consoles and patching bays. At the consoles, the operators have access to system status indication, power level meters showing the transmitter power output, Acc indication of received signal level, and television switching and monitor equipment. Fig. 6 is a block diagram of the baseband system.

AUDIO FOR EARLY BIRD

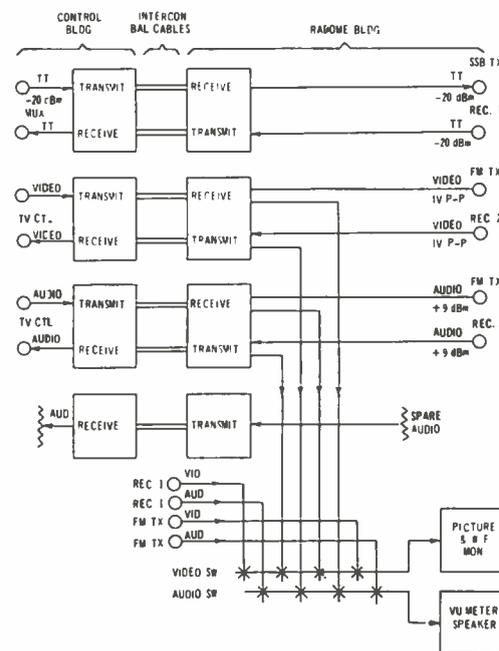
Facilities for receiving audio as a separate carrier were not provided until well into the station development after the plans and characteristics for a communications system using Early Bird were established by ComSAT. These facilities were therefore added onto the existing scheme in the following manner.

Audio signals at standard level are used to drive an 81-MHz FM deviator, separate from the existing exciter but physically located within the exciter enclosure. The audio IF at 81 MHz is added to the video IF at 70 MHz, and the combined signal is upconverted by the exciter in the usual manner and thereby generating the audio carrier at 6400.97 MHz, the North American Early Bird

frequency. The up-conversion process actually generates a second carrier at 6378.97 MHz (below the main carrier) but this is a spurious carrier and cannot be used for signal transmission. The ratio of useable video to audio carrier power at RF is adjusted to the desired value of 13 dB by adjusting the power level of the audio carrier at IF.

In the receive direction, use is made of the existing facilities for receiving two carriers simultaneously. A new local oscillator frequency of 4002.00 MHz was provided for one of the receivers to convert the audio signal for the North American receive frequency of 4092.00 MHz to an IF of 90 MHz. A high quality FM tuner was then tuned to 90 MHz and the audio signal was recovered in a conventional manner. An audio amplifier

Fig. 6—Block diagram of the baseband system.



was used to increase the tuner's output signal level to standard value.

EQUALIZATION

Much of the equipment comprising the satellite communications links introduces transmission non-linearities in varying degrees. These non-linearities, in general, result from variations of group delays, with frequency and from discriminator non-linearities. The latter problem is not too serious since the discriminator non-linearity has been reduced to a very low level by careful design.

Group delay non-linearity on the other hand, is quite significant and special action is taken to overcome it. Significant contributors are the IF amplifiers, side-band filters, and klystron power tube in the transmitting system, the satellite electronics, the IF amplifiers, RF filters and IF filters in the receiving chain.

If the group delay follows a linear or parabolic law across the frequency band, this may be cancelled out by adding passive elements, or "equalizers" which have the opposite characteristic to the circuit. Higher order non-linearities cannot yet be equalized but fortunately they are of quite small magnitudes.

The transmit system group delay contribution is cancelled out first by adding equalizers in the exciter IF path so that the group delay from the deviator to the power amplifier output is essentially a constant.

The satellite and receiver group delay contributions are then cancelled by adding equalizers in the receiving IF path. These equalizers have to be changed whenever the station is working with another satellite, or whenever the IF filter in the receiver is changed because of different signal spectrum widths.

COMMUNICATIONS PERFORMANCE

Many performance tests were conducted at all phases of the station development, but the final system tests were conducted on a back-to-back basis, via a 6 GHz to 4 GHz "test loop translator" which can partially imitate a satellite, or via the Early Bird satellite.

The test loop translator is a frequency conversion device which is connected from a signal sampling coupler at the output of the FM transmitter to the test coupler input point at the input to the parametric amplifier. The translator converts the 6-GHz transmitter signal sample to an IF frequency of 70 MHz and then to the receive frequency of 4 GHz. A variable attenuator inserted in the translator's local oscillator for the

70 MHz to 4 GHz conversion process permits adjustment of the "received" carrier power. Typical performance measurements taken for the FM transmit-FM receive loop using the test loop translator are given in Table IV. Loop measurements on the SSB-transmit-PM-receive loop could not be made since neither the ATS satellite, nor a suitable transponder was available. However, the measurements taken through a special PM modulator and the PM path of the receiver are given in the Table.

The tests made via the Early Bird satellite loop are the most interesting and useful for immediate purposes. Typical telephony, television video and television audio measurement will therefore be given. Noise power ratio measurements using 240 channel noise loading and pre-emphasis were performed on a back-to-back basis using a 2.5-MHz RMS multichannel frequency deviation and an 18-MHz noise bandwidth IF filter in the receiving system. The following readings were obtained:

Slot Frequency (kHz)	NPR (dB)	Weighted S/N (dB)
70	35.0	53.8
534	33.0	51.8
1002	33.0	51.8

These measurements were taken under dry weather conditions and are 1.8 dB better than the minimum CCIR weighted s/n ratio of 50.0 dB. For television, the weighted peak signal-to-RMS noise ratio was measured to be about 50 dB, using a peak-to-peak frequency deviation of 5.5 MHz and CCIR pre-emphasis. This is somewhat below the CCIR recommended minimum but it is equivalent to the performance requirements established by COMSAT for television and is quite satisfactory. Other television performance deviations, such as line time

linearity, were within recommended tolerances.

The audio maximum signal-to-RMS noise ratio was measured to be about 49.9 dB. This is slightly lower than that recommended by the CCITT for type-A broadcast lines but it is still quite reasonable and is in accordance with performance established by COMSAT. This noise is mostly thermal noise, the video-audio crosstalk noise being about 7-dB lower. Audio distortion across the 50-Hz to 10-kHz band was less than 2.4% while the amplitude response was within ± 1.1 dB over the same band.

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TABLE IV—Communications Loop Performance Measurements

Parameter	Measurement
Noise power ratio for 300-channel noise loading, pre-emphasis, and 1-MHz RMS test-tone deviation for high c/N ratios (compare this with Table III)	48.8 dB
Baseband frequency response from 60 kHz to 1300 kHz (300 channel)	+0 dB -3 dB
Video baseband response from 10 kHz to 4 MHz (525 line television)	+0 dB -5 dB
Line-time distortion (linear)	0.5%
Field-time distortion (linear)	2%
Audio frequency response from 30 Hz to 15 kHz for maximum signal on the 7.5 MHz subcarrier and a deviation of 140 kHz. 75 μ sec pre-emphasis used.	± 2.2 dB
Audio distortion over the frequency range	1%
Noise power ratio for 1200-channel noise loading and 0.25-radian RMS test-tone deviation. (PM loop only), high c/N ratio.	40.4 dB

MULTIPATH EFFECTS IN SPACE COMMUNICATIONS

There are occasions when it is not practical to place highly directive antennas on space vehicles. Therefore, in a communication link between two terminals using essentially isotropic antennas, where at least one of the terminals is in the general vicinity of a rough surface (e.g., a planet), scattering from that surface will introduce multipath fading which must be taken into account in assessing the performance of the link. The phenomenon of fading (or time variability of the signal) will, of course, occur only if the terminal or the surface changes position with time. This paper discusses the problem of fading under the assumption that the surface is rigid but the terminal is moving relative to the rough surface. The important systems parameters associated with a given communication link are examined. The parameters to be considered are the depth and rapidity of fading as well as the coherence bandwidth of the system.

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THE communication link to be analyzed in this paper can be described as follows: A probe is falling toward the surface of a planet and transmitting to a distant space ship which makes an angle, θ_2 , with respect to the perpendicular to the average surface (Fig. 1). For the moment, the average surface is assumed to be plane; however, the extension to spherical surfaces will be discussed. Both the transmitter and the receiver are connected to essentially "isotropic" antennas. Because the position of the probe relative to the rough planetary surface is changing with time, fading at the receiver (in the space ship) will occur. To evaluate the characteristics of this fading, an approach based on the Kirchhoff-Huygens principle was used. The basic theory and limitations of this approach were carefully described by Beckmann and Spizzichino.¹ These may be summarized as follows:

- 1) The rough surface is Gaussian with $\sigma/\lambda \gg 1$, where σ is the RMS bump height and λ is the radio wavelength.
- 2) The RMS slope of the surface is fairly small. Mathematically this is written $\sigma/T \ll 1$, where T is the correlation length of the surface undulations.
- 3) The rough surface correlation function is analytic. The mathematical implications of this are discussed by Beckmann² as well as others.
- 4) Shadowing of one part of the surface by another as well as multiple scattering are not important considerations. This is a satisfactory approximation so long as (2) above is satisfied.

AVERAGE SCATTERED POWER

The first quantity to be evaluated is the average scattered power (measured relative to the power in the direct signal). This can be written

$$\bar{P}_s = \int P_o dS \quad (1)$$

Here, \bar{P}_s represents the average scattered power from the extended surface while P_o represents the average scattered power per unit area of surface. From Eq. (10), sec. 12.4.1 of Beckmann and Spizzichino,¹ we may write (with minor change of notation):

$$P_o = \frac{|R|^2}{4\pi} \frac{r^2}{r_1^2 r_2^2} \frac{\cot^2 \beta_o}{\cos^4 \beta} \exp\left(-\frac{\tan^2 \beta}{\tan^2 \beta_o}\right) \quad (2)$$

where $\tan \beta_o = \frac{2\sigma}{T}$ (\approx RMS slope of sur-

face undulations)

$\tan^2 \beta =$

$$\frac{\sin^2 \theta_1 + \sin^2 \theta_2 - 2 \sin \theta_1 \sin \theta_2 \cos \varphi}{(\cos \theta_1 + \cos \theta_2)^2}$$

and R is the Fresnel reflection coefficient for a plane surface.

Angles, θ_1 and θ_2 , and distances, r_1 and r_2 , in the above formulas are indicated in Fig. 1 with the exception of φ (identical with θ_3 of Beckmann and Spizzichino¹) which is the azimuthal angle. The original contribution in this paper is the evaluation, in closed form, of the integral in Eq. (1) which had not been accomplished heretofore. Since it has been assumed that $\tan \beta_o$ (the RMS slope of the rough surface) is a small quantity, the integral in Eq. (1) can be evaluated by the method of "steepest descent."³

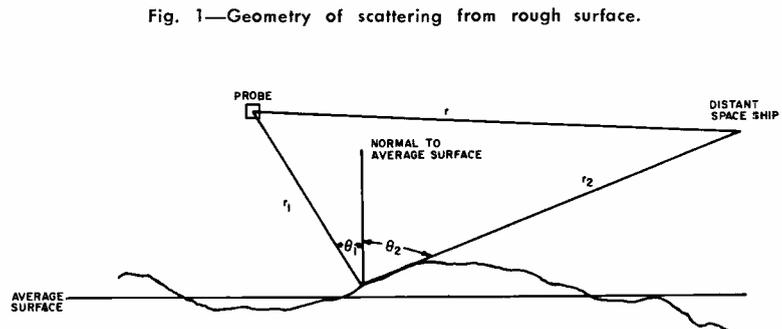


Fig. 1—Geometry of scattering from rough surface.

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The integration leads to the remarkably simple yet important conclusion

$$\frac{\overline{P_s}}{P_d} = |R|^2 \quad (3)$$

where P_d is the power in the direct wave and R (the Fresnel reflection coefficient) is evaluated at the specular point. The moon and Mars, for example, seem to have reflection coefficients typical of dry sandy soil¹ with a dielectric constant $\epsilon \approx 3$. Using this estimate and neglecting ground conductivity, the curves in Fig. 2 are obtained. These curves are essentially independent of frequency.

The horizontally polarized scattered signal is seen to be stronger than the vertically polarized one. For any given polarization, the signal in the neighborhood of the receiver is composed of a direct wave and a Rayleigh-distributed scattered wave whose mean power is some number of dB below the direct wave. This number is a function of the direction θ_2 and is given in Fig. 2. From results presented by Norton, et al.,⁵ Table I was prepared assuming horizontally polarized waves. A similar table for vertically polarized and circularly polarized waves could also be prepared but are not given here. The columns in this table represent several typical directions, θ_2 , while the rows define three different reliability levels, P , that represent usual

design requirement. The numbers in the boxes represent how far down in dB the composite signal (direct plus scattered) is expected to be below the direct signal. This defines a fading range.

TABLE I—Expected Fading Range in dB Below the Direct Signal

$P \setminus \theta_2$	0°	30°	45°	60°	79°
99%	4.7	5.4	7.3	10.6	14.3
99.9%	7.1	8.5	12.3	19.0	24.1
99.99%	9.8	11.9	19.0	28.7	34.0

FADING RATES AND FREQUENCY DIVERSITY

The previous discussion restricted itself to the depth of fading. We now undertake to evaluate the fading rate to be expected. To understand the concept of fading rate as it applies to this situation, it should be recognized that the ground scattered signal can be considered to consist of a sum of rays with random relative phase. As the probe changes its position relative to the rough surface, the phases between the various rays change, and fading (i.e. signal fluctuations) occurs. This fading has a typical period or, equivalently, a bandwidth. Actually, the scattered signal will be beating against the direct signal also. But for almost all geometrical situations, the direct signal will lie somewhere near the center of the band of the ground scattered signal so that the beat frequencies between the direct signal and the ground-scattered signal will also lie within the same fading bandwidth. We will, therefore, restrict ourselves to evaluating the bandwidth of the ground-scattered signal.

It is well known in the theory of random functions that the spectrum and the time auto-correlation function are Fourier transforms of each other. Therefore, knowing one implies knowing the other. We will, therefore, discuss the evaluation of the time auto-correlation function $C(\tau)$ of the random ground scattered signal, $E(t)$. The relation is

$$C(\tau) = \overline{E(t)E(t+\tau)} \quad (4)$$

where the bar denotes the average of the quantity under the bar. For the sake of simplicity, we characterize $E(t)$ by a sum of independent phasors (rays) with random relative phase

$$E(t) = \sum_i E_i \exp(j\varphi_i) \quad (5)$$

From (5), we obtain

$$\overline{E(t)E^*(t)} = \sum_i E_i^2 \quad (6)$$

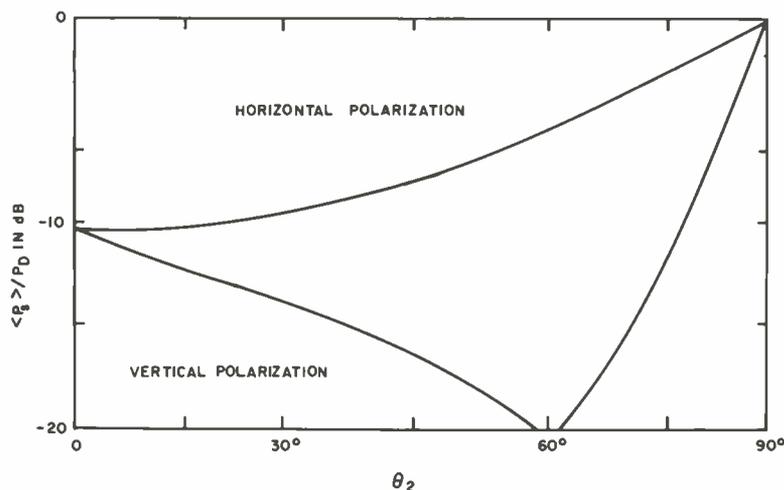


Fig. 2—The estimated average scattered power for the lunar or Martian surface.

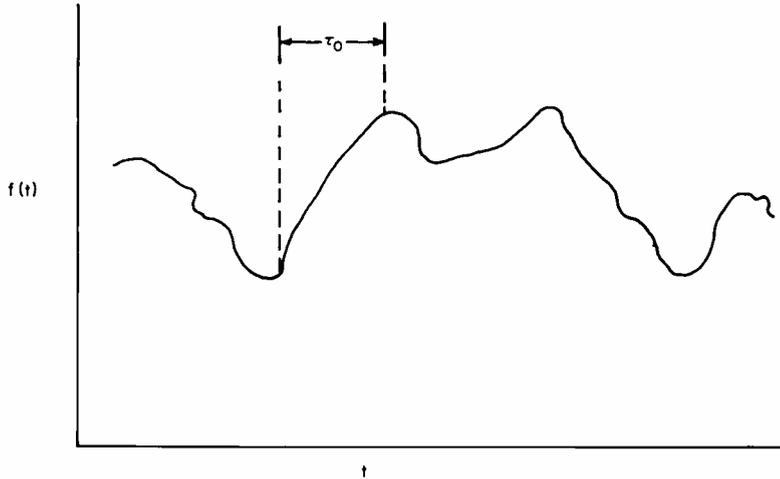


Fig. 3—A record from a hypothetical random function of time.

which is the analog of Eq. (1) with E_i^2 representing P_o . At $(t + \tau)$ we have

$$E(t + \tau) = \sum_i E_i \exp [j(\varphi_i + \Delta\varphi_i)] \quad (7)$$

where $\Delta\varphi_i$ is the systematic (not random) phase change introduced by the motion of the falling probe. Applying Eq. (4) to (5) and (7) yields

$$\overline{E(t)E^*(t + \tau)} = \sum_i E_i^2 \exp (-j\Delta\varphi_i) \quad (8a)$$

For continuous functions instead of discrete variables, Eq. (8a) would be

$$C(\tau) = \overline{E(\tau)E^*(t + \tau)} = \int P_o \exp [-jk(R_o - R_n)] dS \quad (8b)$$

Where $R_o - R_n$ is the change in path length (in a time τ) of the falling probe from an element of the scattering surface. It is assumed that the position of the distant spaceship from the scattering surface does not change in the short period of time, τ .

Using the method of "steepest descent" mentioned earlier, Eq. (8b) can also be evaluated in closed form. The envelope correlation function $R(\tau) = \left| \frac{C(\tau)}{C(0)} \right|^2$ is shown to be of the form

$$R(\tau) = \exp (-\tau^2/\tau_o^2) \quad (9)$$

where

$$\tau_o = \frac{T}{\sqrt{8} kv\sigma \sin\theta_2}$$

for probe falling with vertical velocity, v , and

$$\tau_o = \frac{T}{\sqrt{8} ku\sigma \cos\theta_2}$$

for probe moving with horizontal velocity, u .

Estimates for a particular probe descent toward the Martian surface indicates that $\theta_2 \approx 45^\circ$, $T/2\sigma \approx 10$, $\lambda \approx 1$ m and $v \approx 3$ km/sec. From the above formula, $\tau_o \approx 5 \times 10^{-1}$ sec which implies a fading rate of 2 kHz (i.e., the bandwidth of the fading signal is approximately 2 kHz). The above relation between τ_o and the fading rate comes from the basic property of the time auto-correlation function: τ_o is a measure of the typical fading period while its reciprocal is a measure of the bandwidth of the fading.

To give these symbols a physical meaning, refer to Fig. 3 which shows a short interval of a record of a random function of time. An estimate of τ_o is indicated in the Figure. The function is sketched as being always positive because it is intended to represent a voltage envelope.

Finally, we discuss the question of the coherence bandwidth or frequency diversity; i.e., we try to answer the question, "How far apart do two frequencies have to be in order that the fading at these two frequencies be independent?". The answer will, of course, be some frequency difference, Δf , which is independent of frequency. For frequency diversity, the two frequencies would have to be chosen with a difference greater than Δf . On the other hand, to avoid selective fading the intelligence bandwidth on a given carrier must be less than Δf . In this paper, Δf is evaluated with the aid of the correlation function $C(\Delta k)$ defined by

$$C(\Delta k) = \overline{E(k)E^*(k + \Delta k)} \approx \int \exp [i\Delta k(r_1 + r_2)] P_o dS \quad (10)$$

Again this integral was evaluated by the method of "steepest descent." The structure of $C(\Delta k)$, like all correlation functions, is such that it is a maximum at $\Delta k = 0$ and has dropped to about one-half its maximum value when $\Delta k = \Delta k_o$. One can then write the estimate of the coherence bandwidth as

$$\Delta f \approx \frac{c}{\pi h_o} \left(\frac{T}{4\sigma} \right)^2 \quad (11a)$$

where $\Delta f = \frac{c}{2\pi} \Delta k_o$ and c is the velocity of light. If it is assumed that $\frac{T}{2\sigma} \approx 10$ (which seems to be typical of the moon and Mars), then we may write

$$\Delta f \approx 2.5/h_o \quad (11b)$$

where Δf is measured in MHz and h_o is the height of the probe in kilometers.

APPLICATION TO A SPHERICAL SURFACE

The previous discussion was restricted to a rough surface which, on the average, was plane. However, the same basic method of "steepest descent" can be used to obtain the analogous result for a rough surface which, on the average, is spherical. The results are more complicated to write down; however, for altitudes less than 1/40 of the planetary radius and for angles more than 7° above the horizon, one can use the formulas quoted earlier in this paper with the understanding that the plane surface be drawn tangent to the spherical surface at the specular point. The reason this is so is that the method of "steepest descent" indicates that the effective scattering region is fairly small and is centered on the specular point if the four assumptions listed at the beginning of the paper are satisfied.

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A Tribute to an Engineer's Engineer

THE publication of this issue of the *RCA ENGINEER* is concurrent with the completion of a distinguished professional career at RCA by D. F. Schmit, Staff Vice President, Product Engineering, Research and Engineering. Because he inaugurated the *RCA ENGINEER* in 1955, it is both fitting and timely that the editors render due credit.

Mr. Dominic F. Schmit ("Demmy" to most of his RCA engineering and research associates) has achieved distinction in application engineering, in engineering product design, and in engineering management.

During the past 12 years, the *RCA ENGINEER* editors have had a first-hand glimpse of the product engineering programs carried out under his supervision; however, D. F. Schmit's career accomplishments date back forty-four years, during which time he has held important engineering posts.

EARLY BACKGROUND

A native of Port Washington, Wisc., Mr. Schmit graduated in 1923 from the University of Wisconsin with a BSEE degree. Following graduation, he worked as an engineer with General Electric Company and with E. T. Cunningham Company of New York.

Upon joining RCA Radiotron Division in 1930, Mr. Schmit became Manager of Application Engineering and later became Manager of General Development and Engineering. He was responsible

for supervision of the engineering and development of the metal tube and the early development work on miniature tubes and kinescopes for television. In 1938, he became Manager of Research and Engineering, RCA Radiotron Division, Harrison, N.J.

In 1940, he was named Manager of the New Products Division, Camden, N. J. and four years later was appointed Assistant Chief Engineer of the RCA Victor Division; he was closely associated with the development of RCA's first pre-war commercial television receivers. During World War II, Mr. Schmit coordinated engineering on the airborne "Block" Television System, and other military electronics equipments and tubes. After the war, he became active in shifting engineering activities back to entertainment and commercial products such as black-and-white television receivers, electron tubes and broadcasting equipment. He was promoted to Director of Engineering in March, 1945 and was elected Vice President, RCA Victor Division Engineering Dept. in March, 1946.

High on the list of his post-war projects were the RCA Victor "45" Record Player and Records. Mr. Schmit was deeply involved in the early development, field testing, and FCC hearings which led to the approval and establishment of the color television system in use today—a project involving numerous interrelated electronic products.

Mr. Schmit who had joined IRE as an Associate Member in 1925 received an IRE Fellow Award in 1951. He is a registered professional engineer in New Jersey.

PRODUCT ENGINEERING

In 1954, D. F. Schmit was promoted to the position of Vice President, Product Engineering, reporting to the Executive Vice President, Research and Engineering. In this capacity, he was responsible for coordinating and administering product engineering programs and procedures on a company-wide basis. This included specialized guidance on product engineering matters, corporate engineering support of line management, and provision for a corporate-wide standardization program.

In addition to his continuing duties as Vice President, Product Engineering, Mr. Schmit became Senior RCA Representative, C-Stellarator Associates; this organization, established by RCA and Allis-Chalmers, designed and built a large research facility for Princeton University and the Atomic Energy Commission for advanced studies in thermonuclear fusion.

New Product Engineering services of substantial value to RCA engineers were added such as the RCA Frequency Bureau, General Quality Control, Product Engineering Professional Development, and communications programs; some of the most recent of these activities are cited herein.

THE 'RCA ENGINEER'

Based on engineering depth studies conducted in 1953-1954, it was established that engineers and scientists at RCA wanted and needed a medium for the interchange of professional technical information—and between the engineer and management. Thus, in July, 1955, Demmy Schmit launched the RCA ENGINEER. Dedicated to the publication of professional technical information "by and for the RCA Engineer"—the journal has been perpetuated solely by papers written by engineers and scientists at RCA.

TREND

The Research and Engineering News Digest (TREND) fulfills still another communication need of the engineer and scientist at RCA. Alert to the desire of engineers to be informed on the diverse activities within their company and to understand management trends and objectives, D. F. Schmit launched the TREND publication in 1959.

CURRENT CONCEPTS IN SCIENCE AND ENGINEERING

Mr. Schmit has been aware of the need for engineers to keep up with the rapid technological advances by refreshing and modernizing their abilities and their knowledge. Thus, in 1961, he launched for the benefit of engineering leaders, managers and chief engineers the now highly successful CCSE program. As predicted, this series of courses given by RCA engineers and college professors has led to a demand for more training and further instruction for engineers.

INFORMATION RETRIEVAL AND A LIBRARY NETWORK

Along with the rapid technological advances has emerged an information explosion that has resulted in a serious problem for the engineer who wants to select and retrieve rapidly the information he needs. Over the past two years, studies have indicated the practicality of a library system dedicated to the task of solving such problems; thus, this year an effort has been launched that promises to do just that for the benefit of RCA engineers and scientists.

A VITAL LINK: ENGINEER TO MANAGEMENT

Working behind the scenes, D. F. Schmit has provided a vital connecting link between RCA engineers and RCA business management. This factor alone has greatly enhanced the destiny of many engineering programs and ideas.

The editors and the associates of Demmy Schmit appreciate the opportunity to recognize a job well done.



D. F. Schmit (1935)
Manager of
Research and
Engineering in
Electron Tube
Manufacturing,
Harrison, N.J.

← "The men behind the Electron Guns"; Vol. 2, No. 11 Nov. 1937 Scanner features the RCA Radiotron Engineering Department.

D.F. Schmit (1935) Manager of Research and Engineering in Electron Tube Manufacturing, Harrison, N.J.



D.F. Schmit (1926) with five Tube Division engineers, RCA Lancaster, who were guests at a dinner honoring their receipt of Masters degrees from Franklin and Marshall College. Mr. Schmit spoke briefly on the growth of RCA engineering and the challenges of the future. L to R are: D.F. Schmit, L.E. Siepietowski, H.R. Seelen, J.L. Hudson, R. Saunders, C.P. Smith, L.P. Fox and D.J. Ransom.



D.F. Schmit shown with speakers at 1957 Annual Product Engineering Review at Lancaster plant. L to R: R.W. Engstrom, F.S. Veith, C.W. Thierfelder, E.E. Spitzer, L.P. Garner, C.G. Carne, D.F. Schmit, D.Y. Smith, and C.P. Smith.



D.F. Schmit (Nov. 18, 1958) shown upon receipt of top New Jersey award for best industrial publication. L to R: W.O. Hadlock, D.F. Schmit, and C. Lauderback of N.J. Industrial Editors Association.



D.F. Schmit at the podium during 1963 Corporate-wide Technical Papers Symposium held for more than 70 RCA editors and writers; at right, F.D. Whitmore and C.W. Sall.

Nov. 24, 25—Dec. 1, 2, 1959: D.F. Schmit shown at an Engineering Management Seminar conducted for the benefit of over 300 managers. Also visible L to R: L. Jacobs, R. Trachtenberg, H.W. Collar, J.R. Gates, F.W. Widman, Chairman (D.F. Schmit), D.L. Nettleton, and J.N. Marshall.



REVIEWS OF RECENT TECHNICAL BOOKS BY RCA AUTHORS

Presented here are brief descriptions of technical books which have recently been authored by RCA scientists and engineers, or to which they have made major contributions. The reviews were provided by the authors' Editorial Representative. Readers interested in any of these texts should contact their RCA Technical Library concerning their availability for loan, or the book may be purchased through your usual book supplier. For previous reviews of other books by RCA authors, see the August-September 1965 and August-September 1966 issues of the RCA ENGINEER. RCA authors who have recently published books and who were not cited in these listings should contact the editors, Bldg. 2-8, Camden, Ext. PC-4018.

COMMUNICATION SATELLITE SYSTEMS TECHNOLOGY

(Progress in Astronautics and Aeronautics,
Volume 19)



Edited by
Dr. Richard B. Marsten
*Astro-Electronics Division
DEP, Princeton, N.J.*

This volume is a collection of technical papers drawn mainly from the 1966 Communications Satellite Systems Conference of the American Institute of Aeronautics and Astronautics. Dr. Marsten, who was Program Chairman for the Conference, provides the background for the papers in a comprehensive Preface and also is co-author (with Samuel Gubin of the Astro-Electronics Division) of an article on "A Direct-to-Home TV Satellite System for 1970." The first three chapters of this volume discuss the present state-of-the-art of communication satellite systems and their supporting subsystems and components. Additional chapters describe high-power systems; system concepts, present and future; and a sociological overview. Other RCA personnel whose papers appear in this volume are: Har-

old Perkel, Donald G. Horvath and Stephen C. Blum, John D. Kiesling and William S. Maco, Samuel Gubin and James J. Hawley, all of the Astro-Electronics Division; John Bry of System Engineering, Evaluation, and Research; Karl Solomon of Communications Systems Division; and M. J. Schindler of Electronic Components and Devices. (*Published by Academic Press, New York, 1966; price \$12.00*)

Dr. Richard B. Marsten received the SB and SM in Electrical Communications in 1946 from the Massachusetts Institute of Technology, and the PhD in Electrical Engineering from the University of Pennsylvania in 1951. He has had an extensive and unique career in several major fields of engineering electronics applications, embracing some 19 years of activity. Dr. Marsten has been with the Astro-Electronics Division since 1961. At that time, he was assigned the overall management responsibility for the Spacecraft Electronics Department on space-related communications, command and control, telemetry, signal processing and recording systems and subsystems. In 1964, this responsibility was expanded to include spacecraft camera systems and equipments. His department has contributed extensively to the TIROS, RELAY, RANGER, SERT, NIMBUS, and LUNAR ORBITER programs. Since receiving his first degree in 1946, Dr. Marsten has worked as a research assistant, consultant engineer, and uni-

versity professor. While associated with the Allen B. DuMont Laboratories, Polarad Electronics Corp., and Air Associates, his work was concentrated in the areas of microwave, communications, and display design and development. Upon joining RCA in 1956, he participated in a wide variety of successful programs in sophisticated radar design, and integration and application of advanced electronic techniques. Dr. Marsten is an associate fellow of the AIAA, Chairman-Elect of its National Technical Committee on Communication Systems, and member of its Publications Committee; and a senior member of the IEEE.

COMMUNICATION SYSTEM ENGINEERING HANDBOOK

**Roy K. Andres, E. D. Becken,
Theodor Frankel, R. Guenther,
Norman Hovagimyan, Willard F. Meeker,
S. J. Mehlman, Philip Schneider,
B. Sheffield, Leon Stambler, Jack H. Wolff.**
(See below for division and location)

This comprehensive handbook of communications (edited by D. H. Hamsher of the U.S. Army Electronics Command) is an informed overview and appraisal of the entire field—the result of applying the systems approach to communication engineering. Thus the book not only describes, but also compares and, where possible, evaluates, the alternatives confronting the designer of a communication system. And, in

analyzing the requirements in terms of the possibilities, it facilitates not only optimum design but also improvement of existing systems.

Experts in every aspect of communications have contributed their knowledge and experience to this volume, covering principles, customary practices, variations, and standards. Whenever appropriate, the book provides theoretical material as well as practical data, and includes original concepts and evaluations not published elsewhere.

The chapters, titles and names of the RCA contributors are as follows: Chapter 1: "System Design and Requirements," Roy K. Andres, Manager of Advanced Planning, RCA Communications, Inc.; Chapter 3: "Speech Characteristics and Acoustic Effects," Willard F. Meeker, Engineer, Communications Systems Division; Chapter 7: "Switching Engineering of Switched Systems," Theodor Frankel, Engineering Scientist, Norman Hovagimyan, Sr. Project Member, Technical Staff, Philip Schneider, Manager, Digital System Engineering, and Leon Stambler, Leader, Advanced Switching Techniques, Communications Systems Division; Chapter 11: "Wire and Cable Transmission Characteristics," Jack H. Wolff, Engineering Leader, Communications Systems Division; Chapter 15: "High-Frequency Communication Circuits," E. D. Becken, Vice President and Chief Engineer, RCA Communications, Inc.; Chapter 16: "Radio Relay Communication," R. Guenther, Manager, Advanced Communications Technology, S. J. Mehlman, Manager, Advanced Transmission Techniques, B. Sheffield, Sr. Project Member, Technical Staff, Communications Systems Division. (*Published by McGraw-Hill; 972 pages, 548 illustrations; price \$28.50.*)

SPACECRAFT STRUCTURES



Carl C. Osgood
Astro-Electronics Div.
DEP, Princeton, N.J.

This book presents an engineering approach to the design of spacecraft structures. The techniques of design analysis and of solution synthesis are explored on the basis of the requirements and constraints on a spacecraft structure in

relation to the proposed mission. The discussion is limited to three discrete phases in the life of the spacecraft: launching, enroute, and operational. The author states, "The structural design of aerospace vehicles rests generally on the base provided by classical mechanics and strength of materials, and the discussions and conclusions in this volume . . . represent an implementation of this approach. But there is an additional body of knowledge developed by both theoretical and empirical means, and originating chiefly in attempts to account for the anomalies between data and classical theories . . . The topics discussed have not been, and some may never be, reduced to routine practice, but the forward-looking designer should be able to express, at least qualitatively, a relation between them and his work." The six sections of the volume treat, respectively, mission analysis; design approaches and criteria; analytical techniques; structural types, materials, and methods of fabrication; design examples; and future techniques. (*Published by Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1966; price \$15.95*)

Carl C. Osgood, Member of the Senior Technical Staff, RCA Astro-Electronics Division, received BS and MS degrees in Mechanical Engineering from the University of Maine in 1938 and 1943; an MS degree in Metallurgy from the University of Pennsylvania in 1951, and has completed course requirements for the PhD. Mr. Osgood is Chairman of Mechanical Design Reviews for all AED programs and technical advisor in Mechanical and Materials Engineering for Spacecraft Design. He has been responsible for the mechanical design, construction, and testing of two observation satellites, and was Design Manager for the TIROS and RELAY Spacecraft. Mr. Osgood joined RCA in 1951 and participated in studies of magnetic memory devices, film transports for high-speed cameras, and made analyses of nonlinear servo dampers. Previously, he was a mechanical engineer at the Boston Naval Shipyard responsible for the investigations of material problems and failures. He taught mechanical and metallurgical engineering for 11 years at the Universities of Maine, Vermont, and Pennsylvania. Mr. Osgood has published numerous technical papers and is presently preparing another book entitled "Fatigue Design". He is a member of the New York Academy of Sciences, the American Society of Metals, the Review Board for "Applied Mechanics Review", and is a licensed Professional Engineer in both Maine and New Jersey.

FERROELECTRICITY

E. Fatuzzo and W. J. Merz
Laboratories RCA, Ltd.,
Zurich, Switzerland

(*Due to the authors' location, biographies and photos were not available for this issue.*)

This book gives a physical picture of the ferroelectric phenomena. Special emphasis has been given to the most recent developments of ferroelectric research, which have not been treated in detail in previous books. For example, the switching properties of ferroelectrics, their microwave and far-infrared properties, the lattice-dynamics theory, and the second-harmonic generation are covered in detail. The book is designed for the research scientist as well as for the graduate student. Some of the topics treated are thermodynamic theory of ferroelectrics; lattice dynamics theory; other theories of ferroelectrics; static properties of domains; dynamic properties of ferroelectrics; a physical model for the dynamic properties of ferroelectrics; radiation damage; and applications of ferroelectrics. (*Published by North-Holland Publishing Company, Amsterdam; Copyright 1967; 234 pages; U.S. Distributors: Interscience Publishers, a Division of John Wiley & Sons Inc., New York; price \$11.25*)

INSTRUMENTATION FOR MICROELECTRONICS

**R. Glicksman, L. A. Murray,
R. W. Ahrons, T. Gonda, and
M. F. Lamorte**

(Contributors)

*Electronic Components and Devices
Somerville, New Jersey*

The RCA authors listed above contributed Chapter X, "Instrumentation for Advanced Microelectronic Measurements." The first section of this chapter describes some advanced measuring techniques which employ non-destructive infrared and ultraviolet techniques. These measurements are simple, fast, and accurate, and show promise of extending integrated circuit technology through greater control of material concentration. In the section of opto-electronics, measurement techniques of coherent and non-coherent radiation are described. Measurements of thermal resistance and time resolved spectra of lasers are also given. The discussion of cryoelectronics includes advanced instrumentation in the area of vacuum systems including the critical area of automatic mask changing. Testing of cryoelectronic circuits including the problems of refrigeration and instrumentation to determine operable limits are also described. (*McGraw-Hill Book Co.; price and publication data were not available.*)

THE TWO-POUND RADAR

Guerrilla warfare partially depends on the ability of the enemy to move undetected in foliage or under the cover of darkness and fog. If deprived of this advantage by a hand-held tactical radar, the guerrilla can be interdicted and dealt with by conventional fire power. Now, for the first time, a rugged, lightweight radar is available for use by the combat infantryman to detect moving targets and direct small-arms fire in all weather and visibility conditions. This hand-held tactical radar, which can be directly mounted on the M-79 grenade launcher, the M-16 semi-automatic weapon, or the M-60 automatic area-type weapon, combines the ruggedness, reliability, and simplicity of operation which are essential to all-weather operation in the field.

U. A. FRANK, D. L. KRATZER and J. L. SULLIVAN

Mechanical Integration, Practical Weapon System, and Advanced Signal Processing Missile and Surface Radar Division, DEP, Moorestown, N.J.

WORK on the extremely lightweight radars (sometimes euphemistically referred to as the Two-Pound Radars) began at RCA's Missile and Surface Radar Division, Moorestown, N.J., late in 1965. The entire research and development program has been RCA sponsored and funded. The result was a family of hand-held radars which are the first all-solid-state radars, the first to successfully employ pseudo-random code and the first light enough to be mounted directly on a hand-held weapon. RCA can now offer

U. A. FRANK received the BSME from the University of N. H. in 1947 and did graduate work in instrumentation at Johns Hopkins University. His initial work was with NACA (now NASA) doing basic research on high temperature sensing and control. Other positions included assistant to Chief Engineer at Kaiser Metal Products in charge of automation and development programs. Since joining RCA, M&SR, he was lead mechanical engineer on tactical radars such as AN/UPS-1 and AN/TPS-35. Other assignments included the design, building and installation at the site of Project Marshmallow, the instrumentation of an underground nuclear event, as well as principal project engineer on the two-pound radar during the R&D phase.

J. L. SULLIVAN received the BSEE degree from Rensselaer Polytechnic Institute in January 1951. As a design engineer, group leader, and manager at RCA, Mr. Sullivan was responsible for the information processing design on SPS-12 Search Radar, Bumble Bee, Terror Tracking Radar, UPS-1 Search Radar, TALOS, EMEWS, TRADEX, and MADRE. Recently, Mr. Sullivan participated in the conception, analysis and specifications of several advanced information processing systems for infrared sensing, multi-function phased array ra-

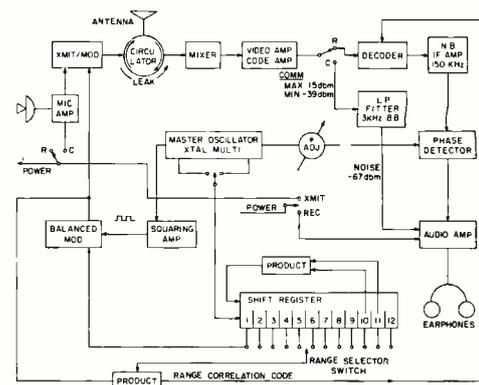
dar, target discrimination radars, multi-static systems and sidelook radar systems. He is a member of IEEE and received a quarterly Technical Excellence citation in 1966. His work on the hand-held radars was recognized by RCA with the David Sarnoff Outstanding Achievement Award in Engineering. He was the team leader of this group.

Simplicity of operation is a key to the usefulness of these radars. Furthermore, the use of the pseudo-random code provides a high degree of security, high resistance to countermeasures and permits use of the device for secure communications. Had all of this been accomplished with complex controls, or requiring extensive training, we would have failed. Experience has shown that

dars, target discrimination radars, multi-static systems and sidelook radar systems. He is a member of IEEE and received a quarterly Technical Excellence citation in 1966. His work on the hand-held radars was recognized by RCA with the David Sarnoff Outstanding Achievement Award in Engineering. He was the team leader of this group.

D. L. KRATZER received the BS from the U.S. Naval Academy in 1947 and the MSEE from Cornell University in 1957. Mr. Kratzer held various engineering assignments from 1947 to 1959 in the fleet and shore establishments of the U.S. Navy. During this diverse naval experience, he was Electronics Material Officer of the USS Boston (GAG-1) and Instructor, Naval Science, Cornell University. Upon completion of his naval service, Mr. Kratzer directed several antenna system R&D projects for military as well as commercial applications at the American Electronics Labs, Colmar, Pa. Since 1960 he has been engaged in radar system analysis and synthesis for M&SR. He presently serves as a system engineer for tactical handheld radar systems and medical electronic products for M&SR. Mr. Kratzer was a member of the team that received the David Sarnoff Outstanding Achievement Award in Engineering for the design of the two-pound radar.

Fig. 1—Block diagram of model 2019 radar system.



with only ten minutes of instruction in the theory and the functional controls of the radar, an untrained enlisted man can start using the radar weapon. Furthermore, most enlisted personnel become quite enthusiastic about the radar's capabilities after about an hour's experience of operating it against a variety of targets.

Presently, there are four models of the two-pound radar. These are listed in Table I. The Model 2019 is a low-power, short-range unit and is described in greatest detail. The Model 2019 radar can detect a man-sized target at ranges up to 500 meters, moving at speeds between a slow walk and 45 mi/h. The target is indicated by an audible tone in a conventional headset, making it unnecessary for the operator to divert his attention from normal visual surveillance. Range switching locates the target within one of twenty 25-meter range segments. Azimuth definition is compatible with the field of fire of infantry weapons. A communications mode is also provided for secure voice communication between two units at ranges up to 1000 meters. The entire unit is battery operated, requiring only 3 watts of input power.

SYSTEM DESCRIPTION

The hand-held radar is an x-band cw correlation system using a pseudo-random code generated by a shift register with a feedback loop. Fig. 1 is the block diagram of the system.

The master oscillator supplies all timing signals for the system including that of the code generator and sensitivity time control (STC) system. The code from the code generator and the STC

Manuscript received April 10, 1967

U. A. Frank



D. L. Kratzer



J. L. Sullivan



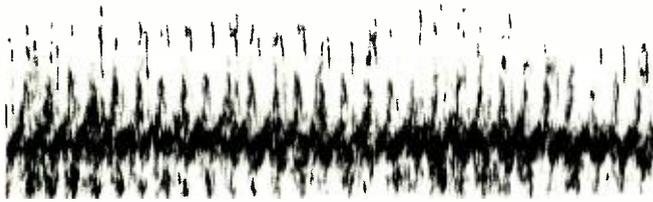


Fig. 3—Man walking toward the radar.

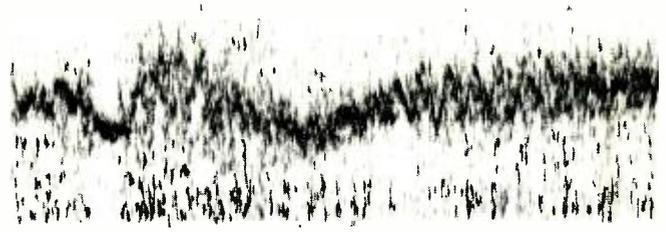


Fig. 5—Horse cantering.

signal from the squaring amplifier, are multiplied in the balanced modulator. This signal shifts the phase of an x-band signal in 180-degree steps corresponding to the modified code.

The signal from the phase modulator is applied to the circulator (diplexer) and then to the antenna where the phase-coded signal is transmitted to, and returns from, the target. The return signal, delayed by the time required to travel the round trip to the target and attenuated by special losses, is sent to the mixer. Also applied to the mixer is the undelayed phase-coded signal leaking through the diplexer; this signal serves as local oscillator for the mixer.

The mixer output is the product of the delayed and undelayed codes on the carrier signals. The carrier signal product is identical to the doppler frequency of the target at low frequencies. The frequencies below 12 MHz are passed by the video amplifier to the decoder where this signal and a similar signal derived from the product of delayed and undelayed codes is also applied. The decoder strips the pseudo-random code from the input signal leaving only the stc signal which has been modulated by the doppler signal. This signal is passed through the narrow-band amplifier where the square wave is reduced to its fundamental sine-wave which remains modulated by the doppler signal. The delayed stc signal is mixed with the adjusted stc sinewave of the master oscillator in the phase

detector. The output signal is stripped of the stc signal leaving only the doppler signature of the target. The doppler signal is amplified and sent to earphones.

Range is determined by choosing the proper delay on the shift register such that the output signal is maximum. Normally the signal is only heard in the range element containing the target.

As the target approaches, the signal strength increases inversely as the fourth power of the range. When stc is applied, the signal increases as the inverse square of range with the net result of reducing the domination of nearby targets.

An examination of the signals from simple applied mathematics will be helpful in understanding the system. The code generated by the shift register, $S_1 = f_1(t)$, where $f_1(t) = \pm 1$. The stc signal, $S_2 = f_2(t)$, where $f_2(t) = \pm 1$. The balanced modulator output (S_3) is the product of S_1 and S_2 . The output of the phase modulator (S_4) is

$$S_4 = S_3 \cos \omega_o t \\ = f_1(t) \times f_2(t) \cos \omega_o t$$

where ω_o is the radar carrier frequency. The local oscillator (leakage) of the mixer is equivalent to S_1 , the transmitted signal. The reflected and delayed signal is

$$S_5 = f_1(t + \tau) f_2(t + \tau) \cos \omega_o(t + \tau)$$

where $\tau = 2R/C$, the round trip delay to the target of range R at C , the speed of light. The output of the mixer (S_6) is the product of S_4 and S_5

$$S_6 = f_1(t) f_2(t) f_1(t + \tau) f_2(t + \tau) \\ \cos \omega_o t \cos \omega_o(t + \tau)$$

The low-frequency portion of this signal passing through the video amplifier is given by

$$S'_6 = f_1(t) f_2(t) f_1(t + \tau) f_2(t + \tau) \cos \omega_o \tau$$

The signal applied to the decoder is given by

$$S_7 = f_1(t) f_1(t + T) f_2(t)$$

where T is the delay determined by the range switch position on the code generator. The output of the decoder (S_8) is the product of S'_6 and S_7

$$S_8 = f_1^2(t) f_2^2(t) f_1(t + \tau) f_1(t + T) \\ f_2(t + \tau) \cos \omega_o \tau \\ = f_1(t + \tau) f_1(t + T) f_2(t + \tau) \cos \omega_o \tau$$

since $f_1^2(t) = 1$, and $f_2^2(t) = 1$.

If $T = \tau$, that is, if the range delay is properly selected,

$$S_8 = f_2(t + \tau) \cos \omega_o \tau$$

The signal is passed through the narrow-band filter converting the square wave into its fundamental. Hence,

$$S_9 = \cos \omega_2(t + \tau) \cos \omega_o \tau$$

where ω_2 is the fundamental of $f_2(t)$. The undelayed stc sinusoidal signal S_{10} is applied to the phase detector together with S_9 .

$$S_{10} = \cos \omega_2(t + \phi)$$

The phase detector output is S_{11} . Thus,

$$S_{11} = S_9 S_{10} \\ = \cos \omega_2(t + \tau) \cos \omega_2(t + \phi) \cos \omega_o \tau$$

The low frequency portion of the signal is

$$S'_{11} = \cos \omega_2(\tau - \phi) \cos \omega_o \tau$$

If ϕ is $\pi/2$, then

$$S'_{11} = \sin \omega_2 \tau \cos \omega_o \tau$$

Let $\omega_2 \tau$ be small, then

$$S'_{11} \cong \omega_2 \tau \cos \omega_o \tau \\ = \frac{\omega_2 R}{2C} \cos \omega_o \frac{R}{2C}$$

At short ranges, this is equivalent to an R^2 power correction. If

$$R(t) = R_o + \dot{R}_o t + \dots + \dots$$

Then,

$$S'_{11} = \underbrace{\frac{\omega_2 R}{2C} \cos \frac{\omega_o}{2C} (R_o + \dot{R}_o t + \dots + \dots)}_{\text{STC Controlled Amplitude}} \underbrace{\cos \frac{\omega_o}{2C} (R_o + \dot{R}_o t + \dots + \dots)}_{\text{Target Signature}}$$

COMPONENT DESCRIPTION

The parts of a delivered 2019 system are shown in Fig. 2. The antenna consists of a stripline dipole phased array, using printed circuit techniques. (Models 3019 and 4019 use a slotted waveguide assembly.) The transmitter consists of an RCA 2N3866 transistor feeding into a cavity and comb-line filter. A step-recovery diode picks the 11th harmonic and the signal goes through an isolator into a four-port circulator. The ports of the circulator are connected to a phase modulator, mixer, and antenna. The

Fig. 2—Parts of the model 2019 radar system.



Fig. 4—Soldier crawling with a rifle at a range of 50 meters.





Fig. 6—Two men running—a jeep slows to a stop and then accelerates.



Fig. 7—Man walking (left) and a woman walking (right).

video amplifier, audio amplifier, decoder, and digital circuitry are all solid state and employ integrated circuits to the greatest extent possible.

The standard battery consists of several nickel-cadmium cells. It is rechargeable from any military vehicle, and will power the system for 12 hours (dusk to dawn). Other battery variations are single voltages with dc-to-dc converters, single-use 12-hour batteries, and a one-hour single-use battery packs weighing about a pound. The earphone has been designed for good low frequency response.

ACCESSORIES

Several accessories expand the range of the basic unit. Available at this time is a manual scanning device, including North orientation and leveling. An automatic scanning device fed by a two-ounce battery can be set to scan 90 degrees and 180 degrees. Either or both scanners may be mounted on a lightweight tripod and adjusted in height from 20 to 60 inches. Either or both scanners may also be mounted on a weapon pintle, available on many line vehicles. The Model 4019 has an automatic target alarm. A red light starts blinking when a target is within range. A remote indication is based on the same threshold circuit.

MANIPULATION

The field manipulation of the radar is very simple. A self-locking hinged sleeve slips on the weapon barrel. A tripod for intrusion protection or indirect fire con-

trol can be set up in less than a minute. After mounting, the operator puts on the earphones and turns the device on; warm-up is not required. The range control is set in the *all-range* position; thus, any target within range of the radar will be audible. Acquiring the target in the *all-range* mode establishes azimuth and elevation. Range is ascertained by switching through the various mutually exclusive 25-meter range bins and re-acquiring the target in one of them. Braille markers around the range-selection knob supplement the visual range indication. Granularity finer than 25 meters is achieved by noting a peaking of volume within the bin as the target moves toward the center of the bin. Range bins of 25 meters were chosen since they correspond to the burst radius of a grenade and to the spray pattern of automatic weapons. In addition, there is a communications *receive/send* mode.

SIGNATURE ANALYSIS

One of the surprising features of this radar's performance has been the clear and distinct signatures various targets produce. Fig. 3 presents a man walking. The abscissa is time, and the ordinate is frequency (i.e., velocity in a Doppler System). Fig. 4 presents a man crawling with a hand weapon. Fig. 5 presents a horse cantering. Fig. 6 is an entire story: starting at left, a jeep enters the range bin and comes to a stop. Men running by the jeep pass it, it starts up and accelerates to catch up with the men.

The extreme right hand portion clearly shows the signatures of both men and jeep. Lines D and E define the wheel motion, proportional to, but faster than, the main body of the vehicle.

While the development of the two-pound radar was reported widely in the American press, it was surprising to receive a news release from the Russian newspaper *Novoye Vremya* (New Times), dated July 22, 1966. This article described the radar as a miraculous gadget which permits detection of the enemy while moving through the jungle! It clearly points out, however, that the radar cannot distinguish between a guerrilla and a woman. This, however, is not the case: the trace in Fig. 7 shows the difference in signature between a man (left) and a woman (right) and the trained ear can ascertain fine nuances in tone better than the oscilloscope. Some close analysis and study has gone into this phenomena and the only conclusions were that there are more moving parts in one case.

FUTURE PLANS

Mounting the radar on various weapons is a continuing cooperative endeavor between Rock Island Arsenal and RCA Fig. 9. An off-weapon-mount is still in the concept stage. However, many other applications are in proposal stages. An adaptation of the radar to vehicle protection is past the systems concept stage. Shipboard signaling, wave height measurements, and several other applications are now being explored.

TABLE 1—Hand-Held Radar Specifications

Model No.	1019	2019	3019	4019
Frequency (MHz)	9250	9250	9250	9250
Detection range (meters)	500 on 0.5m ²	500 on 0.5m ²	1000 on 0.5m ²	1500 on 0.5m ²
Location range (meters)	250	500	1000	3000
Range resolution (meters)	25	25	25	25
Beam pattern (Azimuth x Vert.)	6° x 8°	6° x 8°	7° x 6°	7° x 6°
Power consumption (watts/24 vac battery pack)	3	3	4	5
Signal output	Doppler character	Doppler character	Doppler character	Doppler character & visual alarm
Height (inches)	9	9	11¼	11¼
Width (inches)	12	12	11¾	11¾
Thickness (inches)	3	3	3¼	4¼
Approximate Weight (lbs. less battery and accessory items)	2.2	2.2	2.5	3.0

Notes:

- Communication mode available as an option.
- Tripods and scanner heads are available for use with these radars.
- Mounting considerations available for M-79, M-60, M-14, M-16 weapons.
- All models have pseudo-random code PSK modulation.
- Maximum target speed is 45 mi/h; minimum is 0.75 ft/sec for Models 3019 and 4019, and 2 ft/sec for Models 1019 and 2019.

Fig. 8—On-weapon mount for hand-held radar.



AN APPROACH TO RADIATION EFFECTS IN MOS DEVICES

When an MIS (Metal-Insulator-Semiconductor) device, such as the MOS transistor, is exposed to nuclear or space radiation, the principal effect is not strictly a degradation as is the case in solar cells or bipolar transistors. Instead, the MIS transistor undergoes a change of operating region, which is in the nature of a shift in the bias-dependent characteristics of the device. Other less significant changes are 1) variations in the shape of the characteristic curve and 2) increased leakage current; both of these are effectively degradations. The authors discuss the physics of these effects in MIS devices, briefly survey the known radiation data, and recommend methods of reducing the effects of radiation on the devices.

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UNTIL the advent of the metal-insulator-semiconductor (MIS) devices, the insulator films used on the surface of silicon transistors (and such other devices as integrated circuits and diodes) functioned as inert "passivating" layers, which reduced electrical leakage at the intersection of the surface and the diffused junction. However, in such MIS devices as the metal-oxide-semiconductor (MOS) transistor, the insulator film becomes also an important element of the electrical operation of the device, in that it supports the metal

gate that supplies an electric field to the semiconductor surface and separates these two elements electrically. During early development, mos devices were plagued with serious instability and drift problems caused by ion motion on and through this insulator film, especially at elevated temperature and high-electrical-field conditions. Use of clean handling techniques, development of improved annealing procedures, and modification of source-drain fabrication techniques have made possible, to a great extent, elimination of the insta-

bilities. However, since 1964, it has further been determined that radiation can cause serious drift and degradation in these devices. Although the causes of the drift are distinctly different, the reason for them again is in the insulator film. Some alleviation of these conditions can be accomplished by selection and shielding of the devices and by designing tolerant circuits, but there is still a strong need to "harden" mos devices intrinsically by modifying the insulator film.

This survey attempts to relate sur-

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of radiation environments in fields such as: damage to materials; analysis of space radiation and its effect on space systems; radiation testing of satellite components (TIROS, NIMBUS, RELAY, COMSAT, etc.); post-launch analysis of satellite performance in orbit; and studies of instrument payloads for satellites. He is project scientist of two NASA research contracts in this field. Dr. Holmes-Siedle is presently engaged in experimental and analytical research on nuclear radiation environments, particularly as they affect space systems. He is leader of the Radiation Physics group of the Astro-Electronics Division, and acts for the division as the central contact and consultant in this field. He is also a fellow of the British Interplanetary Society, a member of the IEEE and is listed in American Men of Science. He is the author of eight research papers, a book and several technical articles.

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measurement techniques, but particularly with the physics of radiation damage in MIS systems. He is the author of several papers in the above fields, and is also coauthor of a text book on field-effect transistors. In 1965 Dr. Zaininger received an RCA Laboratories Achievement Award for team performance (shared with A. G. Revesz) for experiments and studies leading to a better understanding of the electrical properties and growth mechanisms of silicon-dioxide films on silicon substrates. Dr. Zaininger is a member of Tau Beta Pi, Eta Kappa Nu, Sigma Xi, and the Institute of Electrical and Electronics Engineers.

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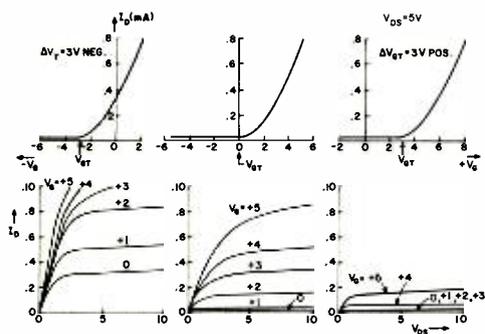


Fig. 2—Effect of threshold shifts on curve trace.

face physics concepts to present-day MIS devices and the problem of ensuring their survival in severe radiation environments. Such environments may arise, for example, from nuclear power generators, from nuclear weapon bursts, or from high-energy particles in space. As well as describing the basic physics of the radiation effects observable in MIS devices, this survey will encompass the range of radiation-induced changes that may occur in mass-produced devices (such as the electronic designer may have to work with) and draw some conclusions on the implications of these effects.

Radiation produces strong changes in MIS devices by introducing a charge into the insulator layer. We use the word "change" rather than "damage" here for a good reason. Radiation actually degrades the performance of solar cells and NPN transistors. In MIS devices, however, the major effect is only a change in the desired operat-

ing region of the device (Fig. 1). For many cases, the device will still be usable if the user can adjust his circuit to "follow" the operating region along the voltage axis and use it under the new electrical conditions. Fig. 2 shows the effect of a shift of the kind shown in Fig. 1 on the well-known form of the operating curve for an MOS transistor. The shift to the left at first appears catastrophic in its effect, until it is realized that the device is still operating properly, but in a different quadrant of its I_D-V_{DS} curve (the depletion mode).

True degradation effects in MOS devices are also sometimes observed when they are subjected to radiation, but, as will be shown later, these effects (unlike the previously described effect) are not universal. A major cause of the degradation effect is the creation of interface states.

MECHANISMS OF RADIATION DAMAGE

An MIS structure (or device) is composed of a semiconductor substrate covered by an insulator layer (of about 50 to 5000 Angstrom), which in turn is covered by a metal electrode or gate (see Fig. 1 insets). The operation of the device is strongly dependent on the charge relationships at the two interfaces. Early work on such relationships was mainly concerned with the semiconductor-vacuum and semiconductor-gas systems. In the latter, there was normally an oxide film 30 to 50 Angstroms thick (formed by incidental oxidation), which was considered part of the surface region. The physics of such surfaces was reasonably well understood and the localized electronic states associated with the surface region were called *surface states*. A distinction was made between *fast*

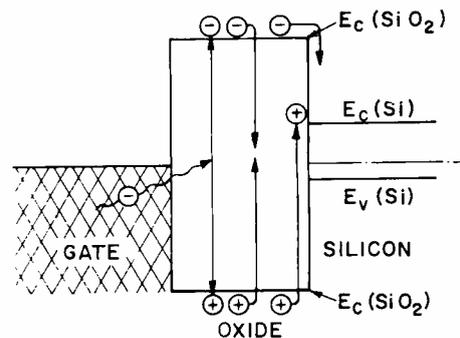


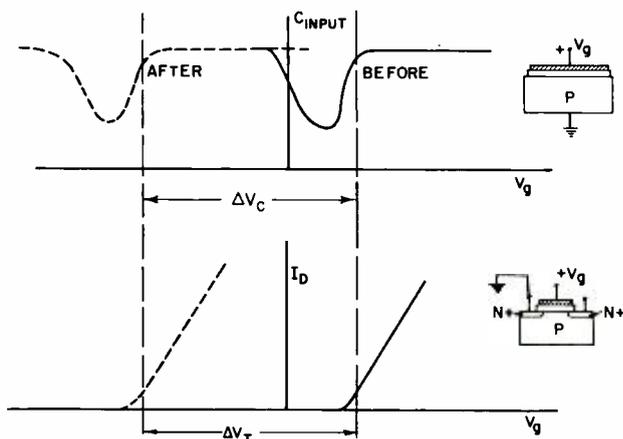
Fig. 3—Model for the effect of electron bombardment of MIS structures.

and *slow surface states*, i.e., between states which could exchange charge rapidly or slowly, respectively, with the semiconductor space-charge region. The slow states were generally thought to be at the outside of the oxide film, and the fast ones at the boundary between the semiconductor and the oxide layer.

MIS physics is a natural extension of this early semiconductor surface physics to a system of two solid-solid interfaces, separated by an insulating film that no longer has negligible thickness. Because of the presence of this film and its two space-charge regions, MIS physics is much more complex than semiconductor surface physics. In addition to this basic complexity, confusion also arises because the concepts and terminology used are mostly inherited from the earlier physics. For example, the distinction between fast and slow surface states is not applicable in an MIS system. Because of the widespread use of the term *surface states*, the expression has been retained but its use is in an operational manner. In this usage, the term *effective surface states* lumps together the effect of work function difference and the two other distinct charge configurations that can be defined for the MIS system:

- 1) *Interface States*: These are stationary electronic states located at the (Gibbsian) plane separating the semiconductor from the insulator. They are analogous to the *fast surface states* mentioned previously. The energy levels for these states can be either within or outside the forbidden gap of the semiconductor. (Simplified energy-band illustrations for the MOS system are shown in Figs. 3 and 10.)
- 2) *Oxide Charge*: This is a charge that is trapped in the "bulk" of the insulator film and cannot communicate with the semiconductor surface. There are two forms of this charge: mobile and immobile. The immobile species is

Fig. 1—Change in operating region of MIS due to radiation exposure.



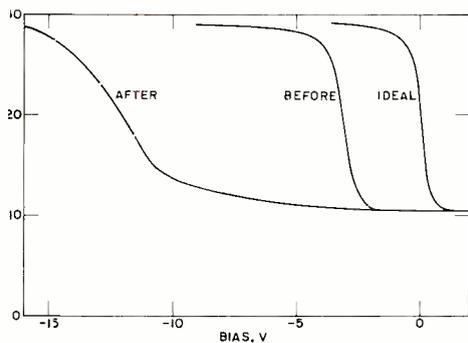


Fig. 4—C-V curves, showing the effect of electron bombardment on an MIS diode that has a distribution of interface states.

mainly due to traps that are part of the intrinsic defect structure of the insulator, whereas the mobile charge is mainly due to ions that are capable of migrating through the insulator, especially during conditions of high field and elevated temperature.

A clear separation of the effective surface states into individual components (including their polarity) is difficult to achieve on the basis of one measurement technique alone. However, the measurement of the capacitance-versus-voltage characteristic at a frequency of one megahertz can yield interesting and meaningful results if proper experimental conditions are established and if the experimental results are carefully interpreted.

In the simplest case, the deviation of the actual C-V curve from the ideal curve (calculated for the same structure) can indicate the presence of surface states. Parallel translations are normally indicative of oxide charge, while changes in the slope of the characteristic indicate interface states. If the actual curve is to the left of the ideal, the charge in surface states is positive, and if it is to the right, the charge is negative. An example of trapped positive charge in an unirradiated sample is shown in Fig. 4 in the curve marked "before".

In this review, we will ignore the mobile oxide charge and focus much of our attention on the fixed oxide charge. As will be seen, however, the interface states can also be very important in MOS transistors (and are probably even more important in bipolar transistors).

In one of the early fundamental investigations of the radiation effects on MIS devices^{1,2} oxygen- and steam-grown MOS capacitors were irradiated with 1-MeV electrons. It was concluded that the exposure of MIS structures to ioniz-

ing radiation results in two distinctly different, permanent effects:

- 1) The creation of interface states (electronic states right at the oxide-silicon interface), and
- 2) The introduction of positive oxide charge (the buildup of a positive space charge within the oxide).

In the first effect, the number and distribution of the interface states produced by a given radiation dose depends upon the state of the interface before bombardment. The higher the density of states before irradiation, the more states will be introduced by radiation, but the lower the density (i.e., the higher the order at the interface), the more difficult it seems to be to introduce disorder. Thus, the destruction of order at the interface by ionizing radiation is probably a cooperative process and, as such, is determined by the perfection of the prebombardment interface structure. The usual case is that in which the original sample shows a wide distribution of interface states over the available energy levels in the forbidden gap of silicon. The density of these states can be, but is not always, strongly increased by irradiation. A typical effect of irradiation on the C-V curve of an MOS device is shown in Fig. 4. In the special case in which a defect is present at the interface, giving rise to a single level of interface states, this single level alone may increase preferentially, giving an unusual "stepped" appearance to the C-V characteristic.¹

The second general effect mentioned is the one that always occurs. The magnitude of the positive oxide charge induced depends upon the defect structure of the oxide, specifically on the density of the hole traps. It is also strongly influenced by the magnitude and polarity of the electric field in the oxide during irradiation, but does not depend on the previous irradiation history of the sample.

Actually, both effects take place simultaneously, but (depending on the initial density of interface states, the total flux, and the value of polarity of bombardment bias) one or the other will dominate for any one particular sample.

The model for the buildup of the positive space charge within the oxide is now quite widely agreed upon. This model, proposed in 1965,³ is summarized in Fig. 3. The incident radiation ionizes the oxide by interacting with the silicon-oxygen lattice and generating electron-hole pairs in the oxide. The holes interact subsequently with trapping sites within the oxide, while the radiation-generated electrons either

recombine with the holes or (because they can migrate easily, particularly if aided by a field) move out of the oxide. The radiation-generated holes are fairly immobile and many of them are captured into stationary traps, giving rise to the observed positive charge. The polarity of the field applied to the oxide during irradiation determines the spatial location of this charge. Some evidence from irradiation experiments on bulk silica indicates that the trapped holes may be localized on a non-bridging oxygen atom (-Si-O⁻) attached to the -Si-O-Si- network.³

The nature of the changes in interface state density involved in the first effect is more difficult to describe. A simple model involving acceptor-like traps with energy levels within the forbidden gap of silicon has been presented.⁴ However, the exact structure of the states cannot yet be determined.

Fig. 5—Change in operating region of p-channel MOS transistors under 1-MeV electron radiation.

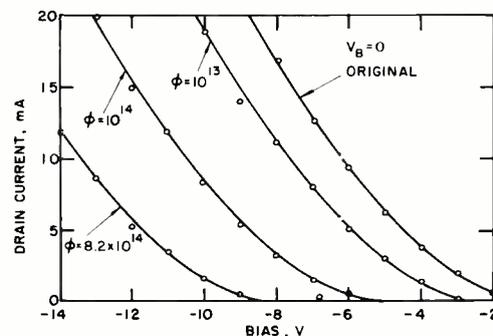
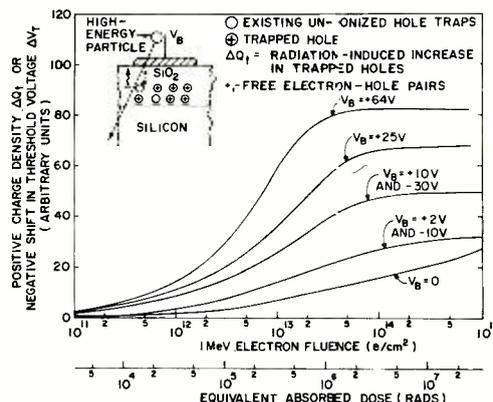


Fig. 6—General form of shift in MIS characteristics under radiation with gate bias, during environment, V_B as a parameter.



**COMMERCIAL MIS DEVICES
RADIATION EFFECTS IN**

At various times, about ten different varieties of MIS insulators have been investigated. However, since most mass-produced devices are made by thermal growth of oxide from the silicon (usually using steam at over 1000°C as the oxidant), it is the metal-silicon dioxide-silicon system that has received the most attention.

As mentioned, the most common form of change in MOS transistors under radiation is a roughly parallel shift of transfer characteristic. Fig. 5 shows a typical form of the shift. This was a typical p-channel MOS transistor irradiated with the gate floating. There is a slight change in curve shape but a major change in the position of the curve. We will call the shift in pinch-off voltage " ΔV_T ". ΔV_T corresponds closely to the ΔV_c of the C-V curve (see Fig. 1). Fig. 6 is a mixture of data from many published sources.⁵ It shows a general form of the change in transfer characteristics of MOS transistors, ΔV_T , under increasing amounts of radiation and various amounts of bias. Note how increasing the gate bias during bombardment (V_B) increases the ΔV_T . For the most sensitive transistors observed, the arbitrary vertical scale can be read directly in volts. Note how negative bias during bombardment has a definite, but weaker, effect in the same direction as for positive bias.

It is of the greatest interest to analyze further this dependence of parameter shifts, ΔV_T , on bombardment bias, V_B . First, Fig. 7 shows two cases of the bombardment-bias dependence of ΔV_c found in MOS capacitors. The vertical scale has been normalized to the number of positive charges (i.e., trapped holes) per square centimeter. This normalization eliminates the effect of different oxide thicknesses and/or dielectric constants from the comparison

of results. However, for the two insulators shown, since they are of the same material (grown silicon dioxide) and of about the same thickness (1,200 Angstroms) though grown in different oxidizing atmospheres, the results for both can be read roughly as ΔV_T on the vertical scale by using the conversion relation: ΔV_T of -10 volts $\equiv \Delta Q_T$ of 1.8×10^{12} holes/cm².

This method of plotting and comparing data from capacitors has been so helpful to the authors that in Fig. 8 the same method is applied to a wide range of published transistor data. The comparison here is more rough and ready, since it is frequently not possible to determine exact oxide thickness of the devices tested (the ΔV_T for a given ΔQ_T becomes larger as the oxide thickness increases). At the same time, since most practical MOS devices have an oxide thickness in the 1000 to 2000 Angstrom region, a crude but practical comparison is possible. This comparison is a tool that will help us to evaluate the present and future state of the art of the MIS device.

In Fig. 8 we see that, in the positive quadrant, the curves follow the square-root dependence of ΔV_T on V_B fairly well, up to a point. Some resemblance to parabolic behavior is also seen in the negative- V_B quadrant.

The next fact to note is that, between "best" and "worst" MOS transistor types shown, there is a very wide range of ΔV_T observed for a given bombardment bias. Also, laboratory-grown capacitors are seen to give better results than mass-produced units. Silicon nitride or MNS devices can be "good" or "bad". The difference seen here between n- and p-channel MNS devices is probably the result of different processes, not of the channel polarity.

The preceding data on the effects of radiation in MOS transistors forms a fairly consistent picture and gives some

hope that most radiation effects in MIS devices can be predicted and brought under control. There are, however, two other effects that sometimes occur in MOS transistors and that are not so well characterized as yet. Fig. 9 shows one such result.

The shift of the transfer characteristic of the n-channel transistor shown was in the direction opposite to that produced by positive charge, while a considerable change in curve shape also occurred. It seems unlikely from experience that electrons would be trapped to any appreciable extent in the oxide. Thus, a more likely explanation is that the generation of interface states is causing the shift. This is borne out by the presence of an accompanying "room-temperature instability" in the characteristic of the transistor. At room temperature, the curve can drift between the positions shown, the direction depending on the gate bias (called "shifting bias", V_s) applied at any time after irradiation. This bias drives the curve in a direction opposite from that expected from mobile charge migration. Fig. 10 shows a possible schematic explanation involving interface states.

Another effect, which occurs in some MOS transistors when operated under drain-source bias, is a strong increase of drain-source leakage current (I_{DSS}). This can be explained as a surface leakage at the point where the contact diodes meet the oxide. The leakage could be caused by positive oxide charge buildup in the oxide region over the diode junction and a resultant inversion layer formation. This inversion layer is important because it can also block current flow in the surface channel.

In summarizing these collected results on mass-produced devices, it can be seen that the strong effect of bombardment bias (i.e., field across the

Fig. 9—Anomalous shift in transfer characteristics of some MOS transistors under radiation, illustrating room temperature instability.

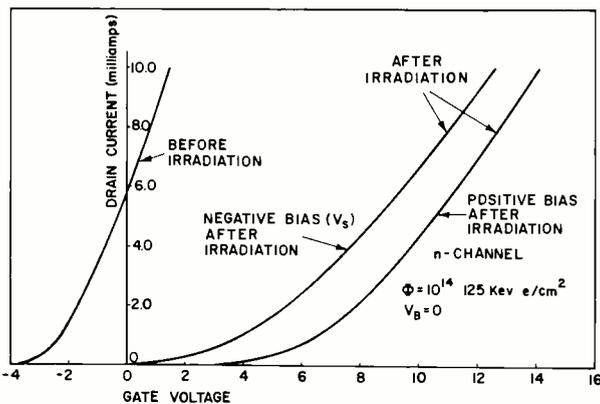


Fig. 10—Mechanism for room-temperature instability (shown in Fig. 9).

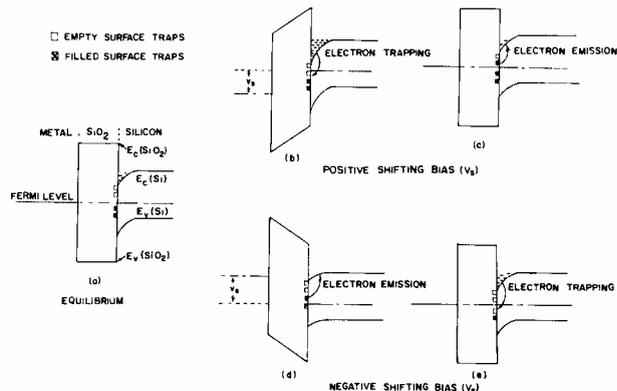
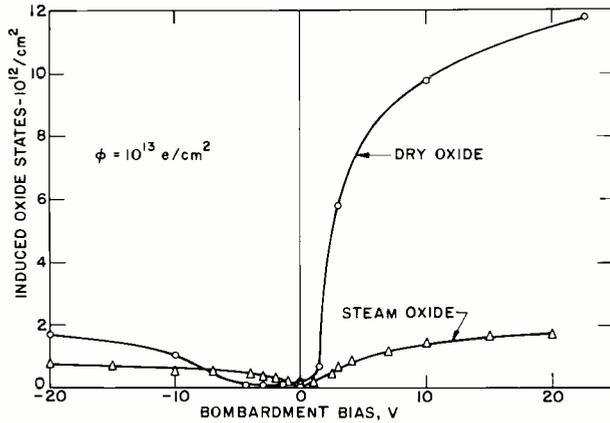


Fig. 7—Effect of 1-MeV electron bombardment of MOS capacitors under bias. A separate specimen was used for each value of bias, but very similar curves were obtained if the same sample was used for all values of bombardment bias.



oxide) during irradiation is very important and probably the effect is an unavoidable result of the form of the MIS device structure. However, if the hole-trap concentration is somehow reduced in the processing, the dependence on bombardment bias becomes much less pronounced. The results on capacitors show that it is possible to reduce hole-trap concentration and that no very exotic steps are needed to effect the reduction. In fact, the general steps being taken in the semiconductor industry to "clean up" the oxide and very closely control fabrication parameters will probably lead automatically to a reduction in the trap concentration and hence the radiation-sensitivity of devices with oxide-gate insulators. In general, the same observations apply to the interface effects described.

It should be noted that serious degradation effects have been observed^{5,6,7} in bipolar transistors under purely ionizing radiation (e.g., x-rays). These effects can be proved to be due to oxide charge accumulations in the passivating layer over the junction regions and are thus probably identical in origin to the MOS oxide effects. Thus many of the conclusions drawn for MOS devices will also apply to the "ionization" or "surface damage" portion of bipolar transistor damage.⁵

APPROACHES TO RADIATION HARDENING

There are two classes of approaches to alleviating radiation effects in MIS devices: change the device itself, and modify the system around the device to reduce the impact of radiation. The latter approach includes the brute-force method of shielding. This has been found practical in space because of the weak penetration properties of the radiation; in the electron and proton environment, even lightweight electronic box covers

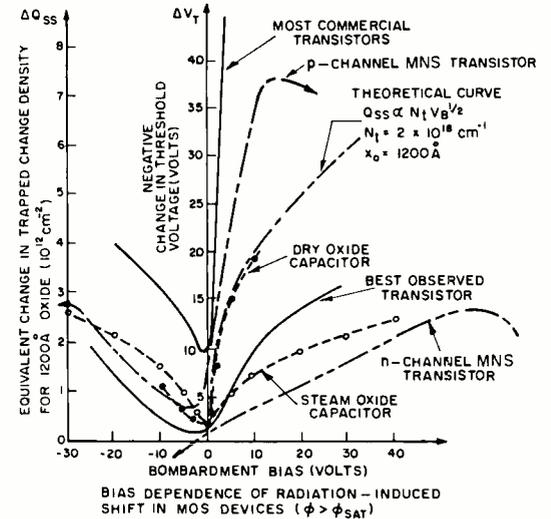
lend a significant degree of shielding. However, the practice will be much less rewarding in weight-limited vehicles exposed to neutron-gamma sources. Other system approaches are circuit design, optimized biasing schemes, and possible high-temperature operation (150 to 200°C operation might produce significant thermal annealing of trapped charge).

The method of preselection has been recommended widely for use with bipolar transistors for use under radiation and is probably applicable to MOS devices as well. It is applicable for cases where the user has little control over the fabrication of the devices he uses. A disturbing amount of batch variation in sensitivity is frequently found in mass-produced, oxide-passivated devices. Indeed, significant variations in radiation sensitivity of oxides, both in MOS and bipolar devices, have been observed across the surface of the same wafer of transistors. Thus, a rapid preselection test of all devices intended for use under radiation (e.g., the actual flight units for a satellite) should be carried out, possibly using a simple radiation source such as a benchtop x-ray machine or an enclosed isotope source. Possibly, the less sensitive devices selected can be annealed back to original condition before use. Table I summarizes these approaches to alleviation of the radiation effects discussed here.

CONCLUSION

The mechanisms involved in radiation damage in MIS devices have been briefly reviewed and it has been shown that: (1) They apply widely to the mass-produced MOS devices now available; (2) There is ground to hope for strong improvements in radiation hardness of MOS devices by finding process techniques which reduce hole-trap con-

Fig. 8—Dependence on V_B of radiation-induced shift in transistors and capacitors.



centration in the oxide; (3) The radiation-induced changes are not usually a true "degradation" but consist mainly of parameter shifts; and (4) The processes concerned are well enough understood and sufficiently predictable that methods of designing circuits and systems to accommodate the radiation effect can be devised.

TABLE I—Silicon Device Hardening Techniques

Method	MOS	Bipolar
1. Oxide Change		
a. Reduce impurities	✓	?
b. Modify growth process	✓	?
c. Use nitride, etc.	✓	?
2. Anneal	✓	✓
3. Preselect	?	✓
4. Tolerant Circuit Design	✓	✓
5. Geometry Modification	✓	✓
6. Dope Bulk Silicon	-	✓
7. Shielding	✓	✓

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COMPUTER DESIGN—SOME PITFALLS TO AVOID

To know about and to avoid some of the pitfalls facing the computer engineer can save both time and money. Certain blind alleys cannot be avoided, and certain unfruitful approaches may be profitable the second time around; however, this is a decision that the well-informed engineer can make most efficiently after reviewing prior art (both failures and successes). This paper reviews and reflects on some engineering decisions of historical interest.

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FOR more than twenty years, engineers have been writing articles about progress in digital computer development at an ever increasing rate. Milestone after milestone has been well-documented and the innocent reader might get the impression that mistakes were never made. Now, as a second generation (men, not computers) heads for the same blind alleys that were explored in the forties and the fifties, it is fitting to write about what we did wrong in those early days. This is not a record of what was done at RCA or is it confined to industry. Universities contributed their share of boners, and goofs were probably made all over the world, although this article is confined in scope to this country.

SYSTEM DESIGN

One of our first wrong assumptions was that punched cards were obsolete. We couldn't believe that people would continue to store, on twenty-square inches of card, information that would easily be accommodated by half a square inch of magnetic tape. Having convinced ourselves of this, we did not concern ourselves with the trivial prob-

lems of transferring data from cards to the computer: tape was the chosen medium. We then faced the problem of preparing tape directly from a keyboard. That problem is now solved; however, when the first business computers were being designed, such seemingly trivial details as back spacing and selective erasing made life miserable.

The original idea of manual preparation of magnetic tape for data input to a computer dates back to the first electronic business machines. It was dropped after a few years only to be revived recently, thus completing the full cycle.

COMPUTER ORGANIZATION

Megahertz pulse rates seemed so unbelievably fast that we convinced ourselves that we had more computer speed than we could possibly use. This incorrect premise resulted in the equally wrong conclusion that only a pure serial machine was justified. All of the bits of a computer word flowed along a single path in sequence.

Later, when we began to realize the error of our ways the pendulum swung to the other extreme and pure parallel

systems (whose costs were exorbitant) were the order of the day. It took approximately six years for the industry to realize that there were advantages in a less extreme approach.

MEMORIES

Probably no single element of the digital computer has been through as many upheavals as its main store. Some of the first machines, taking a cue from MTI (moving target indication) radar used mercury-column acoustic delay lines (Fig. 1). Construction of these "tanks" never really advanced from art to science during the years when they were used. Looking back, they seem to have had every possible disadvantage: their attenuation was approximately 60 dB and the stored information was volatile (that is, it was lost when power went off). Furthermore with long lines in the pure serial machine one could easily spend more time in waiting for the information than in actual data processing.

Since the velocity of sound varies with the temperature of the medium and the coefficient is quite large for mercury, something had to be done to keep the number of pulses stored in a tank constant. An interesting wrong approach was AFC (automatic frequency control). The basic pulse rate of the computer could be varied to make the tank hold the correct number of pulses. Unfortunately, this solution did not account for the tanks being at different temperature! In due time, computers with constant-frequency oscillators and controlled heaters on the mercury tanks were designed and built.

The acoustic line has seen many improvements. Solid quartz has replaced the temperamental mercury, but long before that change these devices were abandoned by the computer industry.

A second attempt to solve the mem-

Fig. 1—Mercury delay line.

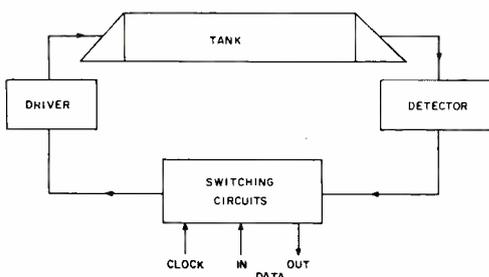
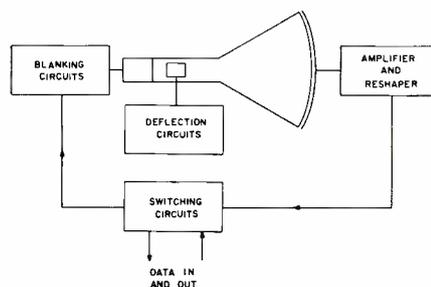


Fig. 2—Electrostatic memory.



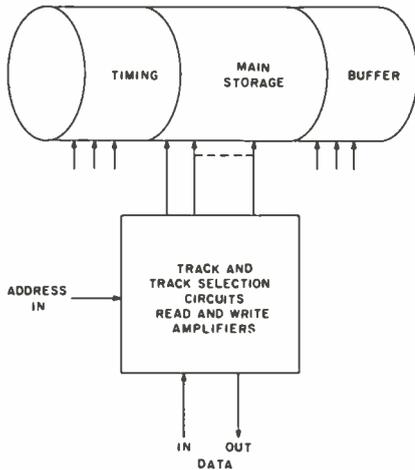


Fig. 3—Magnetic drum.

ory problem was the electrostatic storage tube (Fig. 2). This barely got to be used before it, too, was replaced. In its most popular form (which, incidentally was *not* espoused by RCA) it was an attempt to store binary information as a matrix of two different types of charge patterns on the face of an ordinary cathode ray tube. Among its various disadvantages were the need for dangerously high voltage, extreme susceptibility to noise, and the requirement for precise deflection circuits in a system which otherwise contained no critical amplitude sensitive devices.

Probably the next main memory was

G. D. SMOLIAR received his BSEE in 1939 from CCNY. After eight years in civil service in various positions he entered the field of digital computers in 1947 as a design engineer in the company that eventually became the Univac division of Sperry Rand. For the past 20 years he has worked continuously in this field as a designer and as a supervisor of engineers. He joined RCA in 1962 as a manager of computer product design. In 1967, Mr. Smoliar was named Staff Engineer; in this activity, he also serves as EDP Technical Publications Administrator and as a Consulting Editor on the RCA ENGINEER. Mr. Smoliar is a Registered Professional Engineer in the state of Pennsylvania and holds two patents on computer components. He is the author of several articles pertaining to digital equipment and teaches logic design to engineers in the RCA training program.



the magnetic drum (Fig. 3). This seemed to be a reasonable solution. It was non-volatile and inexpensive and its storage capacity was adequate. We told ourselves that by "minimum latency coding" (selectively placing the information in storage) we could program around the long wait for the right word to come up. If that had been true we might still be using drums as main memories. It was not, and we finally arrived at core storage.

Meanwhile, at the other end of the memory-size spectrum, the single-bit storage element, the flip-flop, was being re-examined. It seemed extravagant to continue to use two tubes for this circuit which has not changed in the years since Eccles and Jordan. So, in the early fifties, the dynamic flip-flop (Fig. 4) or "Ring-around-the-Rosy" circuit came into use. It had a single tube which drove a one-pulse delay line whose output was returned to the tube input. Its two stable states were: no signal, and a steady stream of pulses. It was indeed a one-tube flip-flop. Unfortunately it had no other advantages. In fact, measured by the usual criteria of cost, speed and what we now call fan-out, it was decidedly inferior. It seems to have passed into oblivion.

The three-stable-state flip-flop should also be mentioned. Aside from being a departure from standards, there is nothing fundamentally wrong with this idea. In each computer there seem to be a few places where hardware could be saved with this gadget. Usually it does not pay to use it, because it is special; therefore it is discarded only to be re-invented on the next project! We have been down that road before, several times.

CIRCUITS

Looking back, it could almost be said that the digital computer was developed

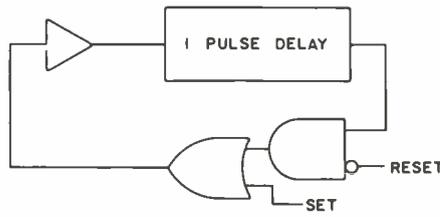


Fig. 4—Dynamic flip-flop.

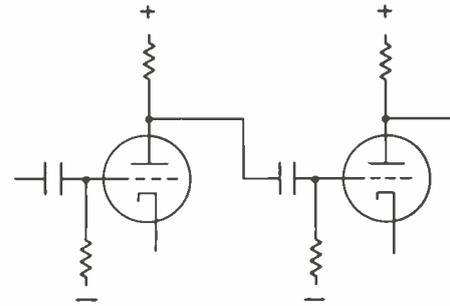


Fig. 5—AC coupling

too early. It certainly seems pathetic to have built those five-thousand-tube, fifty-kilowatt monsters (which frequently failed due to the failure of a single tube heater) while the transistor was just around the corner. Had we waited just a few years a lot of hardware that was doomed to obsolescence would not have been built. However, using tubes by the hundreds was not our only weakness.

For a while AC coupling was popular (Fig. 5). This meant that because of capacitors, or similar interstage coupling elements, there was a lower limit to the frequency components of the signals we could transmit. We found ourselves in the ridiculous position of having to investigate, at each point in the equipment, the exact nature of the normal pulse pattern. Of course, failure to take into account the abnormal pulse pattern gave us a generous helping of trouble-shooting problems.

But in some ways our cure for this unfortunate situation was worse than the sickness. When we needed response all the way down to DC we used direct-coupling (Fig. 6); that is, input to a tube grid and output at a plate some

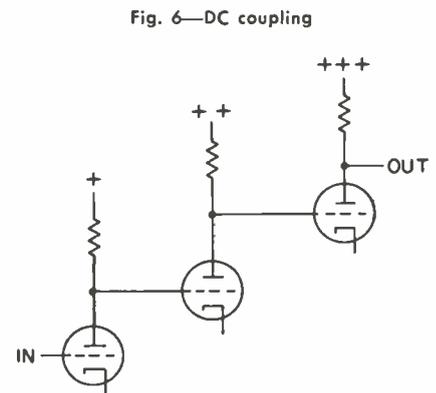


Fig. 6—DC coupling

sixty volts higher. If our logic took us through several of these stages we had signals whose base lines were hundreds of volts apart and our power supply requirements were such as to make strong men (and power supply designers) weep.

It is almost obvious that in this unhappy state standard circuits, as we now know them, were virtually nonexistent. At times we seemed to have more circuit designs than tubes in those computers.

One interesting approach during the AC coupling, dynamic flip-flop days was based on maximum power output. Each device (tube, in this case) has a load impedance to which it will deliver maximum power. Therefore, computers were designed in which pulse transformers (Fig. 7) coupled the tube outputs to the low-impedance loads. (One part of that scheme is still in use.) It was realized then that the complement of a signal is used as frequently as the signal itself. For that reason each transformer had two secondary windings and the "barred" and "unbarred" signals were always available.

Another abandoned system was that of pulse magnetic amplifiers. After we tired of constantly replacing burned out tubes and before transistors were adequate and inexpensive, magnetic amplifiers were given a whirl. These little tape-wound toroids could be set to "positive" or "negative" remanence by the signal. Then a power pulse interrogated the core. Depending upon the polarity of the state in which it had been left, it looked like either a high or a low impedance to the power pulse. This device amplified, delayed, and, if necessary, inverted the signal. Combined with diode gating it provided all necessary logic functions (Fig. 8). Unfortunately it was slow (under 1 MHz) and expensive. As transistor prices decreased and speeds increased, the pulse magnetic amplifier went out.

HUMAN ENGINEERING

During the design of the first computers, the engineers watched for all places where manual switches would be helpful in trouble-shooting. They also looked for points in the circuit whose state could be observed with indicator lamps. For example, all of the bits of the instruction being executed were brought out to energize neon bulbs, and at each lamp a lever switch could modify that bit (before the era of the lighted pushbutton) and could even fix its state to prevent its being changed in the course of the program. This collection of lights and switches told the operator everything he needed to know

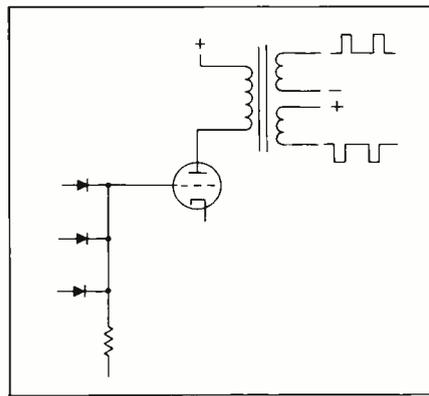


Fig. 7—Amplifier with pulse transformer.

and maybe even more. The console became so big that it became impossible to keep track of everything that was displayed (Fig. 9). Furthermore twenty-five square feet of that sort of complexity could frighten away prospective customers who were looking for machines that their clerical employees could master.

The pendulum swung and simplicity became the key word (Fig. 9). The designer was permitted to use no more than a dozen lights and switches. He took advantage of the fact that several functions could be combined in one illuminated switch assembly; nevertheless, there was considerable overflow from the simple console and so the "maintenance panel" was born. In theory, this second panel displayed information that would only interest the repair man; in fact, the operator learns to use every control and indicator that is available and, regardless of popular opinion, they make his job easier.

CONCLUSION

It seems that computer designers in the past would frequently take an extreme position and stick with it until forced to change. This article is a plea for moderation. Product design is not so simple that it is governed by universal truths.

Another lesson can be learned from this brief account: we frequently become so enamored of our own ideas and value originality so highly that we neglect to study the past. Engineers could think even before the days of the sampling scope. Use what is good even if it is old and try to avoid making the same mistakes that have been made before. I do not say that every abandoned idea is now worthless. The important point is to know why certain approaches were tried and dropped. Then you will be able to consider them as possible solutions to new problems when many of the old restrictions may have disappeared.

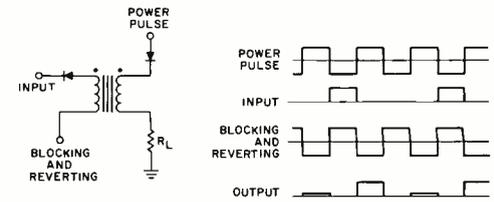
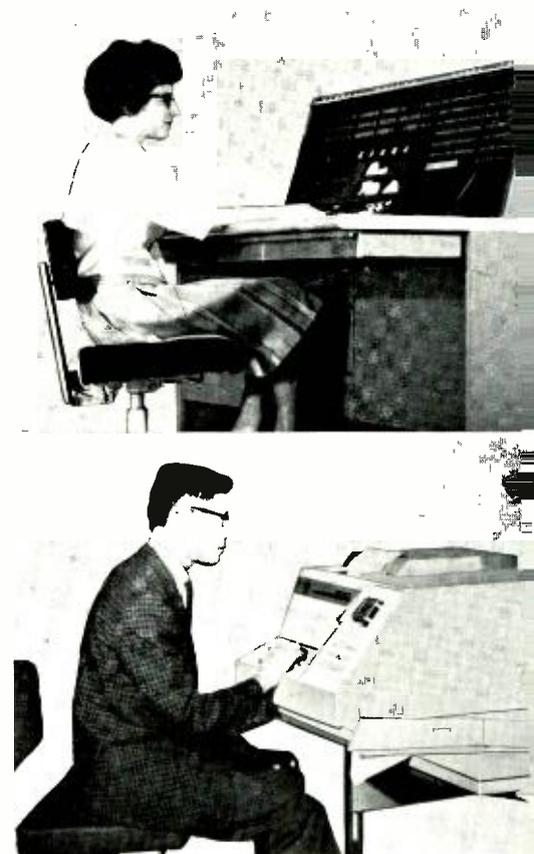


Fig. 8—Pulse magnetic amplifier.

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Fig. 9—Consoles, large and small.



TV APPLICATIONS OF MOS TRANSISTORS

The latest RCA insulated-gate *n*-channel silicon field-effect transistors incorporating both single and dual gates have great flexibility for use in a large number of television circuits. Although originally designed for use in RF amplifier stages, these units have the desirable combination of high transconductance and low feedback capacitance which assures excellent performance in many other television stages, including low-level-video, chroma, and AGC circuits. This paper describes several RCA MOS transistors which are being developed especially for television receivers. It also reviews field-effect transistor theory of operation, clarifies the basic designations relating to the various types of field-effect transistors, and discusses several TV-circuit applications in which these devices have been used.

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WHEN the junction-gate field-effect transistor first became commercially available in the early 1960's, it was apparent that these devices with their high input impedance and their wide dynamic range would eventually be used in television receivers. The later development of the insulated-gate field-effect transistor provided improved gain and frequency performance and further encouraged those who were working toward the all-solid-state television receiver. Because the majority of insulated-gate field-effect transistors produced to date are of metal-oxide-semiconductor construction, they are more commonly known by the acronym MOS.

THEORY OF OPERATION

Field-effect transistors (FET's), whether junction-gate or insulated-gate, are called *unipolar devices* because current flow depends upon majority carriers alone (as in a resistor). The amount of current flow is controlled by an electric field. In contrast, current flow within the better known bipolar transistor depends upon the interaction between majority and minority carriers.

The FET uses a semiconductor material such as *n*-type silicon, which may be visualized as a very small bar. At one

end of this bar is an ohmic contact called the source; at the other end is another ohmic contact called the drain. When the FET is "on," charge carriers (electrons in *n*-type silicon) flow through the channel, which effectively joins the source to the drain. This charge-carrier flow is possible because the channel has the same electrical conductivity sign as the source and drain, i.e., if the source and drain are *n*-type silicon, the channel must also be *n*-type. The flow of charge carriers in the channel is controlled by elements called gates which are close to the channel.

The interaction of a gate and the channel is comparable to that between the two plates of a capacitor. In this instance, a charge placed on one plate (the gate) induces an equal but opposite charge on the other plate (the channel). Depending upon the polarity of this induced charge in the channel, the conductivity of the channel is either decreased or increased from its initial zero-charge state.

If the channel is electrically conductive even in the absence of applied voltages, the FET is called a *depletion-type*. If the channel does not become conductive until a gate-bias voltage is applied, the FET is referred to as an *enhancement-type*.

GLOSSARY

bulk (substrate) gate—a gate formed by the bulk-to-channel junction
channel—the conductive path between the source and drain regions of an FET
depletion-mode operation—FET operation with a reverse gate-source voltage to decrease drain current from the value at $V_{GS} = 0$
depletion-type FET—an FET which has appreciable conduction from source to drain at $V_{GS} = 0$ and which can always be operated in depletion-mode and to varying degrees (depending on construction) in the enhancement mode.
drain—the ohmic contact through which charge carriers flow out of an FET
enhancement-mode operation—FET operation with a forward gate-source voltage to increase drain current from the value at $V_{GS} = 0$
enhancement-type FET—an FET which is in the "off" state at $V_{GS} = 0$ and which therefore will not operate normally in the depletion mode
forward bias—that gate-to-source voltage which, when increased, causes an increase in channel conductivity
gate—the element or elements of an FET which control the flow of charge carriers between source and drain
***n*-channel**—a channel in which the charge carriers are electrons
***p*-channel**—a channel in which the charge carriers are holes
reverse bias—that gate-to-source voltage which, when increased, causes a decrease in channel conductivity
source—the ohmic contact through which charge carriers flow into an FET

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O. P. Hart



J. A. Dean

JACK A. DEAN received the BS degree in Electronics Engineering from Indiana Institute of Technology in 1957. From 1950 to 1954 he served with the U. S. Air Force as a Staff Sergeant in Radio Equipment Repair. He joined the RCA trainee program in 1957, and was assigned to Electron Tube Test Engineering in Harrison in 1958. He has been a member of the Tube Applications Laboratory since 1960, and the Special Products Development Group since 1965. He is a co-inventor on one patent and a co-author of several published papers. He was awarded the Alpha Gamma Upsilon Scholarship Award in 1956.



W. M. Austin



D. M. Griswold

WAYNE M. AUSTIN received the BS degree in Electrical Engineering from the University of Illinois in 1957 and the MS degree in Electrical Engineering from Rutgers University in 1961. He served as an electronics and flight officer in the Marine Corps from 1948 to 1953, before being released to inactive duty with the rank of captain. In 1957 he joined the RCA graduate study program, and was assigned to the Entertainment Tube Applications Group in the Receiving Tube Engineering Activity of the Electron Tube Division in Harrison. He has worked on the development and application of electron tubes for entertainment applications, on audio amplifiers, tape recorders, television and FM radio tube applications, and has written evaluations on competitive electron tubes and receiving-tube applications. He is currently working on transistor applications in color television receivers. He has published eight articles and received one patent on electron tubes and tube applications. He is a member of Tau Beta Pi, Sigma Tau, and Sigma Xi.

DAVID M. GRISWOLD, a graduate of Drew University, joined RCA as an Engineering trainee at Harrison, N. J. in July of 1951. From 1952 until 1957 he worked extensively on the design and development of test circuits for transistors and other semiconductor devices. During 1957 he worked as an Industrial Applications Engineer on high-frequency transistor applications and co-authored a paper on the drift transistor which was presented at the IRE International Convention of 1958. He was then Manager of the Rating Laboratory at the Somerville plant for three years, and Manager of Test and Reliability Engineering for another year. As a Senior Engineer in the Consumer Applications Department from 1962 to 1965 he was responsible for evaluation and applications work related to the development of the MOS field-effect transistor. In 1965 he received the Spring Conference Outstanding Paper Award of the IEEE Group on Broadcast and Television Receivers. As a member of the Special Products Development Department from 1965 to the present, he has continued to work on development of field-effect transistors. Mr. Griswold is a member of the IEEE. He has been RCA's representative on the JEDEC JS-8 Committee on Consumer Product Devices since 1959 and chairman since 1963. He is also a member of the JS-9.1 Committee on Field-Effect transistors.

$V_{DS} = 15 \text{ V}$; $I_D = 5 \text{ mA}$; common source, triode-connected (unless otherwise specified)

Drain Current ($V_{GS} = 0$)	16 mA
Gate Cutoff Voltage ($I_D = 50 \mu\text{A}$)	-4 volts
Forward Transconductance	7300 μmhos
Input Capacitance	6 pF
Feedback Capacitance	0.12 pF
200-MHz Maximum Available Power Gain	20 dB
200-MHz Maximum Usable Power Gain (unneutralized)**	12.6 dB
200-MHz Maximum Usable Power Gain (neutralized)	16 dB
200-MHz Noise Figure*	4 dB

TABLE I—Typical Characteristics of RCA Dev. No. TA2841

* Matched and Neutralized.
** Circuit loaded for a maximum skew of 20% in the bandpass characteristic.

$V_{DS} = 15 \text{ V}$; $V_{G2S} = +4 \text{ V}$; $I_D = 8 \text{ mA}$; common source, tetrode-connected (unless otherwise specified)

Drain Current ($V_{G1S} = 0$)	18 mA
Gate—No. 1 Cutoff Voltage ($I_D = 100 \mu\text{A}$)	-3.0 volts
Gate—No. 2 Cutoff Voltage ($I_D = 100 \mu\text{A}$; $V_{G1S} = 0 \text{ V}$)	-3.0 volts
Forward Transconductance (Gate No. 1 to Drain)	11,000 μmhos
Input Capacitance (Gate No. 1 to Source)	5.0 pF
Feedback Capacitance (Drain to Gate No. 1)	0.03 pF max.
200-MHz Maximum Available Power Gain	20 dB
200-MHz Maximum Usable Gain (Unneutralized)**	20 dB
200-MHz Noise Figure*	4 dB

TABLE II—Typical Characteristics of RCA Dev. No. TA7149

* Matched and Neutralized.
** Circuit loaded for a maximum skew of 20% in the bandpass characteristic.

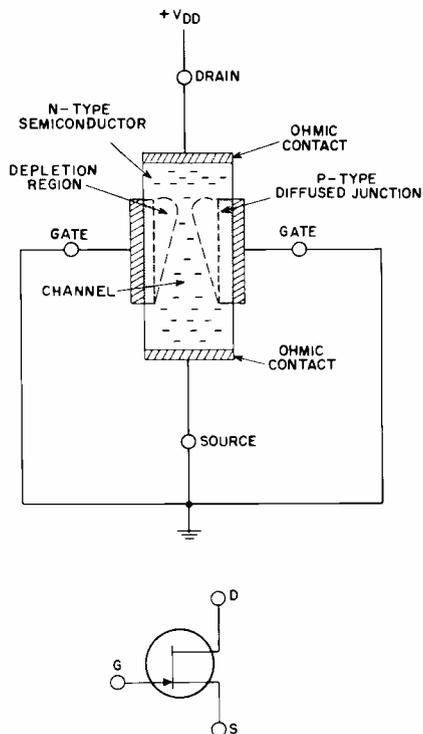


Fig. 1—Schematic diagram and symbol for junction-gate FET.

As shown in Fig. 1, *p-n* junctions serve as the gate electrodes in the junction-gate FET. When these junctions are reverse-biased, a depletion region is formed in the vicinity of the junction, and the addition or subtraction of charge at the junction will alter the area of the depletion region. Because the channel cross-sectional area is a function of this depletion region, its electrical conductivity is correspondingly altered.

As long as it is reverse-biased, the junction-gate FET exhibits a relatively high input resistance, but forward bias causes this resistance to drop sharply. This result is similar to that which is encountered when a vacuum-tube grid is biased positive in relation to the cathode.

The insulated-gate FET has a metal gate electrode which is separated from the channel by a thin dielectric layer, as shown in Fig. 2. Like the junction gate, this insulated gate can also deplete an adjacent channel of its active charge carriers when reverse-bias voltage is applied. However, the insulated-gate FET is unique in that the conductivity of the channel can be substantially enhanced by application of a forward bias to its gate. The gate leakage resistance re-

mains high with either forward or reverse gate bias.

Because the channel of an FET is resistive, current flow through the channel causes an *IR* drop. If the gate is held at the same potential as the source, the *IR* drop causes the potential difference between the gate and the channel to increase at points in the channel which are successively closer to the drain. This progressive increase in the transverse electric field successively depletes the channel of charge carriers and produces a wedge-shaped depletion region which tends to restrict current flow to some maximum value. If the gate is referenced to some potential other than that at the source terminal, some other maximum value of current will flow in the FET. Fig. 3 shows a typical family of *I-V* curves which results when the gate-to-source potential is fixed at several different values while the drain-to-source voltage is varied. Vacuum-tube engineers will recognize these curves as being quite similar to those of the pentode tube.

ELECTRICAL CHARACTERISTICS

The FET family includes both depletion-type and enhancement-type devices;

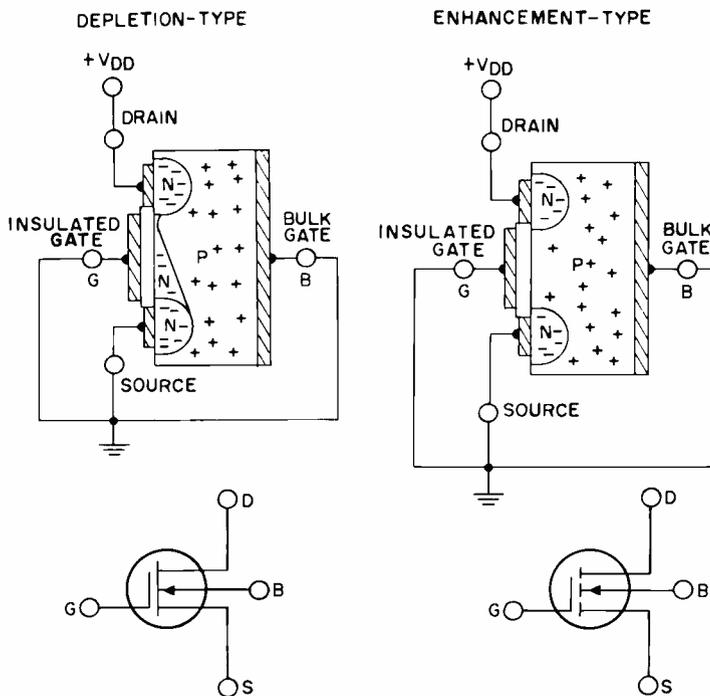
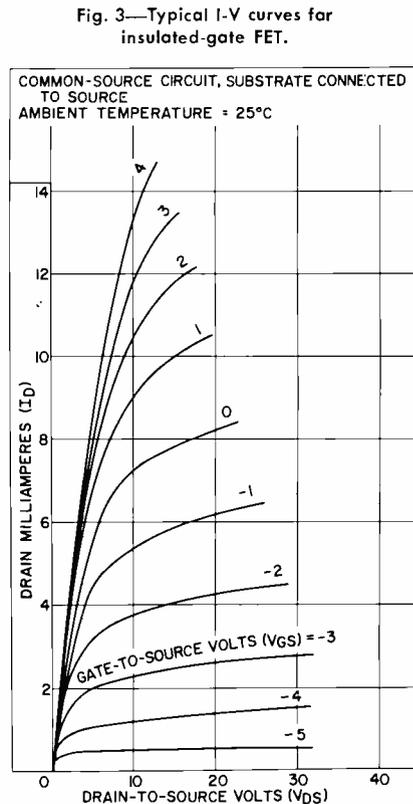


Fig. 2—Schematic diagrams and symbols for insulated-gate FET's.



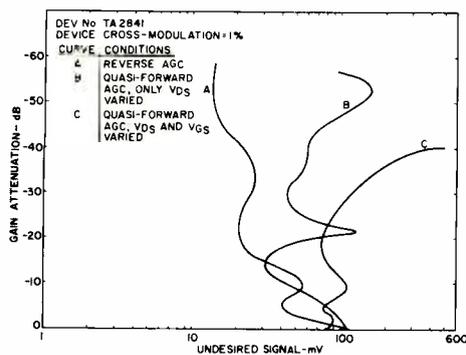


Fig. 4—Effect of AGC methods on cross-modulation performance.

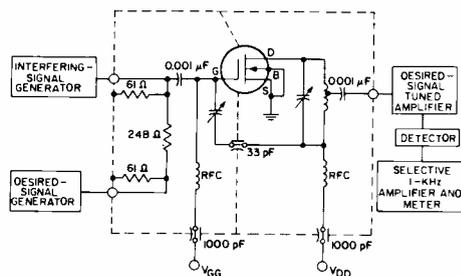


Fig. 5—Test setup used to obtain data shown in Fig. 4.

each type has different operating characteristics. For example, some depletion types may be operated only in the depletion mode, while others may be operated in both the depletion and the enhancement modes.

RCA Dev. No. TA2841 is a depletion type intended for operation in the depletion mode. It is an *n*-channel silicon device which is intended for, but not limited to, VHF applications. The TA2841 has the MOS structure and four leads, which are connected to the source, drain, insulated gate, and bulk junction gate. The characteristics of the bulk junction gate have not yet been fully specified on the TA2841, so this element is normally connected to the source or to the same dc potential as the insulated gate. However, the bulk gate does have a transconductance of about 1,000 μ mhos which can sometimes be used to advantage, as discussed later. Typical key characteris-

tics of the TA2841 are shown in Table I.

The RCA Dev. No. TA7149 is also a silicon *n*-channel depletion-type MOS transistor; however, it is distinguished by the presence of two insulated gates placed serially along the channel length. Typical characteristics for the TA7149 are summarized in Table II.

APPLICATIONS

VHF Amplifier

When the 3N98 MOS first became commercially available, its inherently linear forward transfer characteristics made it a natural candidate for RF-amplifier applications. However, its gain was insufficient for most of the VHF TV channels.

The new TA2841 was designed to remedy this shortcoming. It has the necessary characteristics to meet the RF-amplifier gain and noise requirements for all thirteen VHF channels.

Present VHF field-effect transistors are sharp-cutoff devices, and this characteristic normally leads to degraded cross-modulation performance when reverse gate voltage is used for AGC. Because the TA2841 ratings permit only a small forward gate-bias voltage, it is limited almost completely to reverse-AGC operation.

Fortunately, it is possible to simulate forward-AGC without actually applying forward voltage to the gate. This method of gain control is called *quasi-forward-AGC* to distinguish it from the usual forward-AGC system.

Quasi-forward-AGC can be accomplished by use of another semiconductor device as a shunt control amplifier, either in series or parallel, to control the drain-to-source voltage of the TA2841 amplifier stage. The drain-to-source voltage reduction may be accelerated by simultaneous application of a limited amount of forward AGC to the gate. As mentioned previously, this voltage must be within the maximum positive-gate-voltage rating of 0.6 volt for the TA2841.

A comparison of device cross-modulation curves is shown in Fig. 4. Curve A shows the effects of reverse-AGC alone. Curve B shows the reduction in cross-modulation which results from the introduction of the basic quasi-forward-AGC system, and curve C shows the further improvement effected when quasi-forward-AGC is used in conjunction with limited forward-AGC voltage applied to the gate. It should be emphasized that these curves are valid as a demonstration of relative cross-modulation performance. In any application, the absolute magnitude of the tolerable interfering signal is a function of the particular input-circuit impedance used. The data

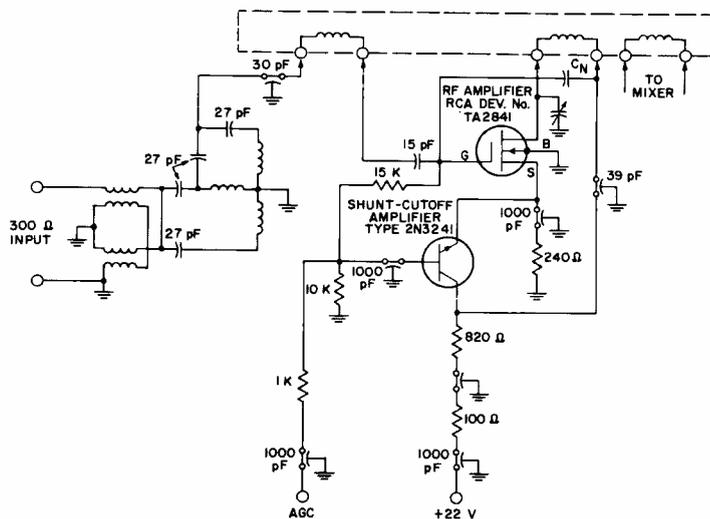
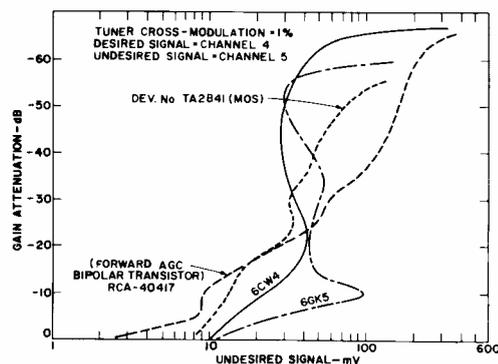


Fig. 6—TA2841 RF amplifier using Quasi-Forward-AGC.

Fig. 7—Cross-modulation performance of television tuner using RF stage of Fig. 6 and of commercial tuner using bipolar transistors.



for the curves of Fig. 4 was obtained in the test configuration shown in Fig. 5.

The TA2841 has been tested as an RF amplifier in a television tuner utilizing a parallel quasi-forward-AGC system. The oscillator (RCA 40237) and mixer (RCA 40236) are typical forward-AGC bipolar transistors. A schematic diagram of the RF stage is shown in Fig. 6. As a positive AGC voltage is applied to this stage, the drain current increases and causes the voltage drop across the bypassed drain resistor to increase. In addition, the 2N3241 shunt cutoff amplifier draws collector current through the same drain resistor, and causes a further substantial decrease in drain-to-source voltage with AGC action. The reduction in drain-to-source voltage causes a corresponding reduction in stage gain. The shunt cutoff amplifier also allows the forward gate voltage of the TA2841 to reach, but not exceed, its rated limit of 0.6 volt.

Channel 13 tuner voltage gain to the gate of the first IF stage is approximately 37 dB. Corresponding noise factor is 5 dB, and at least 45 dB of gain reduction can be realized by application of AGC to the RF amplifier stage. In Fig. 7, cross-modulation characteristics of this tuner are compared with those of commercial tuners that use either bipolar transistors or vacuum tubes in the RF-amplifier stage.

The new TA7149 dual-gate MOS transistor holds the promise of further improvement in VHF performance because it has higher transconductance, lower noise figure, and even lower feedback capacitance than the TA2841. In addition, its two serially arranged insulated gates can be biased to custom-tailor its transfer characteristics. If the TA7149 is operated in an RF-amplifier stage in such a way that gate No. 1 is the signal gate and gate No. 2 is at AC ground, it has many of the characteristics of two vacuum triodes arranged in the well-known cascode configuration.³

When gate No. 1 is used for the input signal and gate No. 2 reverse AGC voltage reduces the drain current, the input and output capacitances of the TA7149 remain relatively constant, as shown in Fig. 8. This effect helps to minimize related bandpass shifting in VHF applications. If special circumstances warrant it, the input-capacitance variations can be reduced even further by application of about 10% of the total reverse AGC voltage to gate No. 1.

At the higher frequencies, circuit impedances are such that the TA7149 is unconditionally stable when matched and can be operated in an unneutralized circuit for the upper VHF tv-channels. The

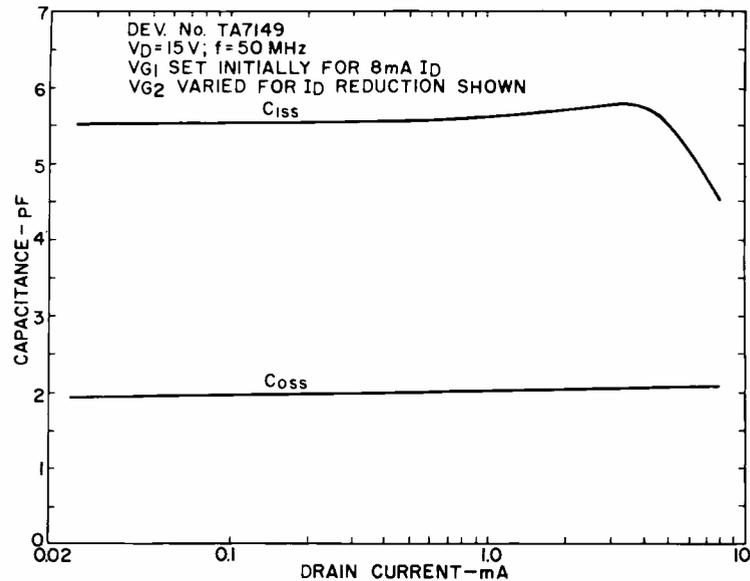


Fig. 8—Effect of drain current on input and output capacitance of the TA7149.

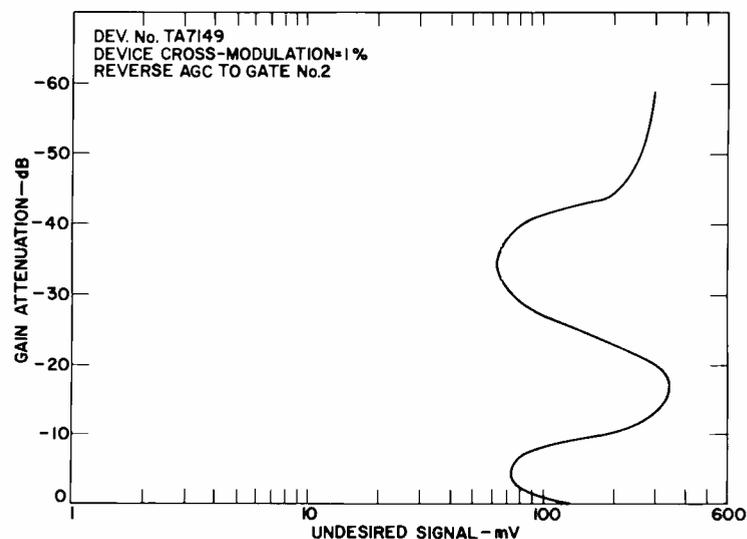


Fig. 9—Cross-modulation performance of the TA7149.

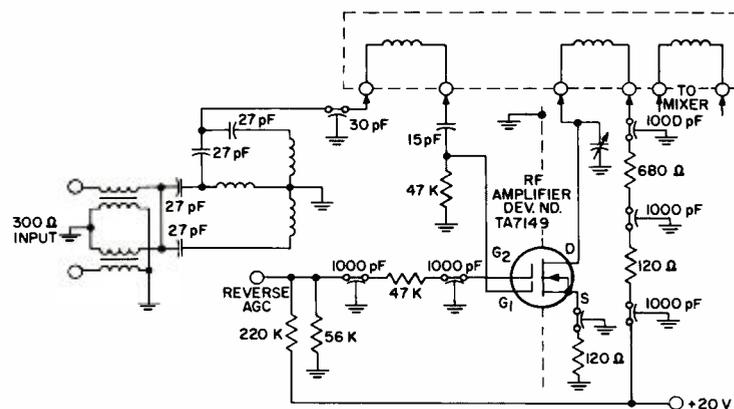


Fig. 10—Unneutralized TV tuner RF-amplifier stage using the TA7149.

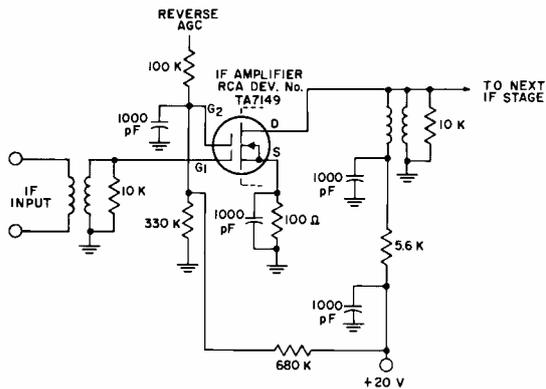


Fig. 11—Unneutralized TV IF-amplifier stage using the TA7149.

usual precaution of shielding input from output should be observed.

At the lower VHF tuner frequencies, gain can be maximized by neutralization of the TA7149 amplifier stage. However, if the Channel 2 maximum usable unneutralized gain is sufficient in a particular tuner application, the circuit design engineer has the option of operating the RF stage unneutralized across the entire tuner frequency spectrum.

TA7149 admittance parameters measured at 44 MHz yield a calculated maximum available gain figure of 35 dB. At this same frequency the calculated maximum usable gain unneutralized is 32 dB. At 200 MHz the calculated maximum available gain figure is 20 dB.

The TA7149 power gain, measured in a test fixture at 200 MHz, substantiates the calculated value. The same test fixture and operating conditions provide a typical device noise figure of 3.5 dB. Typical device cross-modulation performance as a function of gain attenuation in a fixture similar to that used for the TA2841 is shown in Fig. 9. The lower input resistance of the TA7149 suggests that its use would result in better tuner cross-modulation than that presently obtained with the TA2841.

An unneutralized TV tuner RF amplifier stage using the TA7149 is shown in Fig. 10. With drain-to-source voltage at 15 volts and a drain current of 8 milliamperes, Channel 13 tuner voltage gain to the first MOS transistor IF amplifier is 37 dB.

An unneutralized TA7149 TV video IF-amplifier stage is shown in Fig. 11. Measurements on the single stage sub-

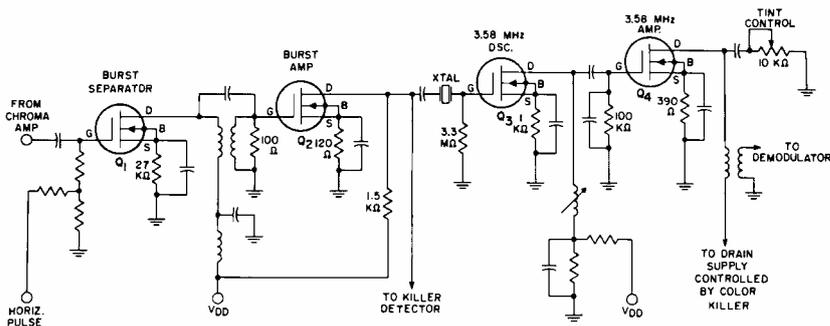


Fig. 12—Four-stage TA2841 chrominance synchronizing circuit.

stantiated the calculated 44-MHz device gain figures noted previously.

Color Synchronizing Circuit

The chief function of the chrominance (color) synchronizing circuit is to keep the receiver 3.58-MHz oscillator precisely in step with the master 3.58-MHz oscillator at the television transmitting station. The link between transmitter and receiver is provided by an eight-cycle burst of the 3.58-MHz carrier frequency, which is transmitted during the horizontal-blanking interval immediately following the horizontal-sync pulse.

Fig. 12 shows a four-stage circuit in which Q_1 , the first TA2841 amplifier stage, is biased close to cutoff by the voltage drop across the large 27,000-ohm source resistor. The time constant of the source resistor and its bypass capacitor is such that the peak of the horizontal keying pulse at the gate turns this stage on just long enough to amplify the burst signal alone.

In Q_2 , the second TA2841 common-source amplifier stage, this burst signal is further amplified to the high level required for proper activation of the 3.58-MHz injection-lock oscillator stage. The crystal, excited by the burst signal, rings synchronously with it and thereby "locks" the local 3.58-MHz signal into synchronism also.

A TA2841 in the injection-lock oscillator stage, Q_3 provides several advantages over other types of devices used previously. Because there is no "grid-current" associated with an MOS transistor, the TA2841 oscillator is not disturbed by any of the complications normally caused

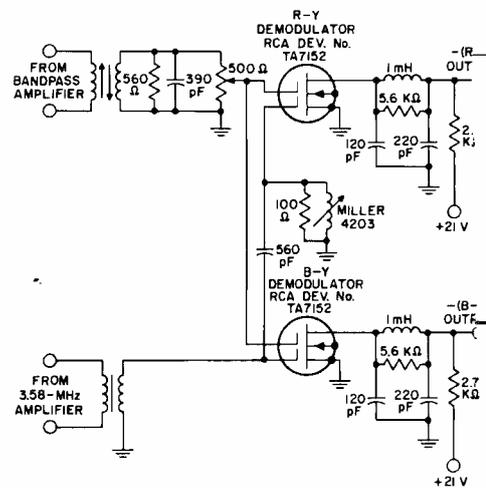
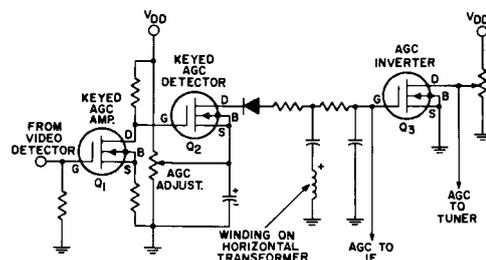


Fig. 13—Color-demodulator circuit using the TA7152.

Fig. 14—Three-stage TA2841 AGC circuit.



KEEPING SCORE IN SPACE—USAF SPACETRACK

One of today's most significant applications of on-line computer systems is in the acquisition of space-object information by the USAF SPACETRACK System. This article summarizes major improvements effected in the data gathering capability of one of the system's important sensor sites. Unique processing concepts are presented, and the increased utility of the sensor site to the system is evaluated.

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THE USAF SPACETRACK System is a combined world-wide network of Air Force space sensors, terminal equipment, and alternate control facilities which combine to detect, track, catalog, identify, and provide data on all man-made objects in space. This system (Fig. 1) under management of the Air Defense Command (ADC) performs many roles including the support of efforts by research and development agencies on further systems. Since the first launch of a space object in 1957, the object population has grown to over 1100 today and is still growing.

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Hannah F. Duncan

SPACETRACK AND BMEWS

The Ballistic Missile Early Warning System (BMEWS) Site III at Fylingdales Moor, England, is a contributing radar sensor in the USAF SPACETRACK System. The utility of BMEWS to the system, as an important secondary mission, had not been fully realized. As the program was organized, only a limited amount of real-time satellite discrimination could be realized, there were limited tracking features, and observations could not be selectively transmitted to the Space Defense Center (SDC), the nerve center of the system. The development effort objectives established for improvement were:

- 1) Provide increased real-time satellite discrimination;
- 2) Provide a wide range of automatic satellite tracking features; and
- 3) Allow observations of selected satellites to be transmitted to the SDC.

On the surface, maintenance of a catalog of 1100 satellites does not appear to warrant such a highly sophisticated system. However, the orbital parameters of some 10% of the object population change enough in just one day so that, if the current observations of the objects are not used to provide new orbital parameters, the space objects could become unrecognizable.

Just as the new astronomer maintains an accurate knowledge of the existing

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H. Richard Headley



James J. Duncan

gaged in BMEWS operational engineering and computer program configuration management work for ADC. Mr. Headley is a registered professional engineer in the State of Pennsylvania and a member of the Operations Research Society of America and the Society of Automotive Engineers.

JAMES J. DUNCAN received a BS (Hon.) in Aeronautical Engineering from the University of Glasgow in April 1958 and then joined De Havilland Propellers, Ltd., and became responsible for design, supervision and analysis of rocket vehicle trials. In 1960, he joined the Saunders-Roe Division, Westland Aircraft, Ltd. where he gained programming experience on both analog and digital computers in a wide range of scientific and operational research applications. Mr. Duncan joined RCA Great Britain, Ltd. in 1962. He participated in the final design, check-out and was responsible for successful integration of the Satellite Information Processor program for Fylingdales. Following official USAF and Hq. FC program acceptance, he was responsible for the continuing development of the operational SIP program, and for establishing and directing the SPACETRACK group which handles all satellite information reaching the site. He joined the Missile and Surface Radar Division in 1965 and was assigned to the Colorado Springs program coordination office. He was responsible for the design, check-out and installation of the MIP/SIP program at site. His current duties, as Deputy Technical Director, include responsibility for the programming effort being carried out in Colorado Springs. Mr. Duncan is a member of the Royal Aeronautical Society.

star background in order to recognize a new star or comet, so must the SDC maintain its catalog in order to recognize a newly launched object or changes occurring in existing satellites. The system is presently geared to take high-priority action on any observation of an object with an unknown identity. Within a very short time it must decide whether this observation represents a new object or if the particular sensor has failed to identify a known satellite. In the former case, the system alerts other sensors of the presence of a new object so that its orbital and physical characteristics may be determined as soon as possible. If the background is not properly maintained, the system would rapidly saturate itself with high-priority unknown processing.

SATELLITE DISCRIMINATION

The Satellite Discrimination portion of the program classifies such radar observations as:

- 1) Objects of doubtful quality not warranting further processing;
- 2) A known satellite;
- 3) An unknown object having the proper dynamic characteristics to be a satellite; or
- 4) An unknown object which does not appear to be a satellite.

The order of the classification process is just as stated in the preceding sentence; in theory, the dynamic-characteristics test should precede step 2 to avoid a possible marginal radar observation being identified as a known satellite. Such observations tend to contaminate the orbital-element updating process at the SDC. Practically, the dynamic-characteristics test is too time consuming to perform on every observation in this real-time situation.

Since the radars scan for satellites at a fixed elevation angle (angle above the horizon) it is possible to establish a minimum range below which an observation could not have been a satellite (Fig. 2); such a test is the final step in preliminary filtering which effectively rejects nearly one-third of the total amount of radar data.

When a radar observation survives the preliminary filtering, a comparison with predicted satellite penetrations is attempted. Time-ordered, predicted penetrations in radar parameters are prepared in advance each day on magnetic tape from the satellite orbital-element magnetic-tape library. Radar parameters in the comparison process are time, range, doppler (or range rate), azimuth and elevation. Since predicted penetrations do not correspond exactly to actual penetrations, extrapolations are made to predict one of the position parameters

of the actual measurement. Azimuth or elevation is used as the position parameter in the calculation of extrapolation time; the choice is made on the parameter having the higher predicted rate. The parameter with the higher rate is normally expected to be the better position measurement. An iterative process is used to compute a time interval (Δt); this is a period over which it is necessary to extrapolate the prediction to establish the measured position. All predicted parameters are extrapolated by this computed time, Δt . A fairly accurate extrapolation over several-hundred seconds of time is possible because the first two derivatives of each basic parameter are available. The typical formulation of this extrapolation is:

$$X_{P \rightarrow A} = X_P + \Delta t \cdot \dot{X}_P + \frac{\Delta t^2 \ddot{X}_P}{2}$$

where X is a specific radar parameter (range, range rate, azimuth or elevation); $P \rightarrow A$ is the transition from predicted to actual; P is predicted; and Δt is as computed by the iterative process.

Following the prediction extrapolation, time, range, doppler, azimuth, and elevation differences are formed between the predicted and the measured values. When these differences are less than preset limits, a quantity representing the apparent spatial separation of the prediction and the actual measurement is computed. If this quantity is less than its preset limit, the satellite identity for this particular prediction becomes a candidate for being the actual observation. All other predictions available at this particular time are subjected to the process just described. The final choice

Fig. 1—Simplified USAF SPACETRACK system flow chart.

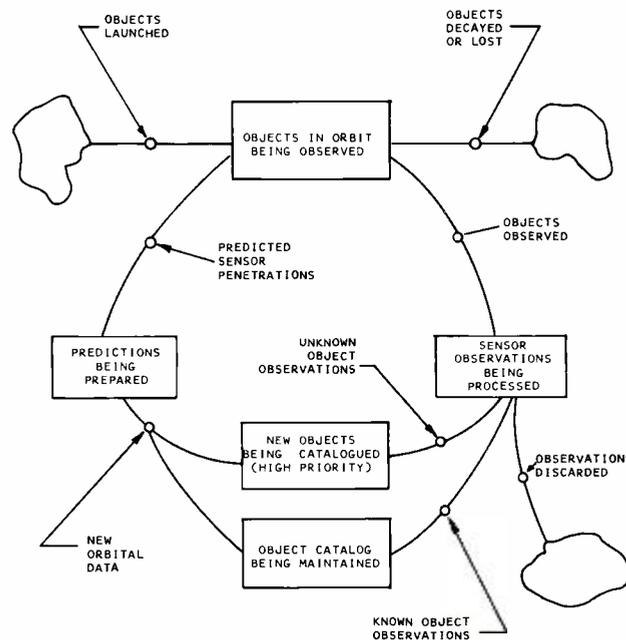
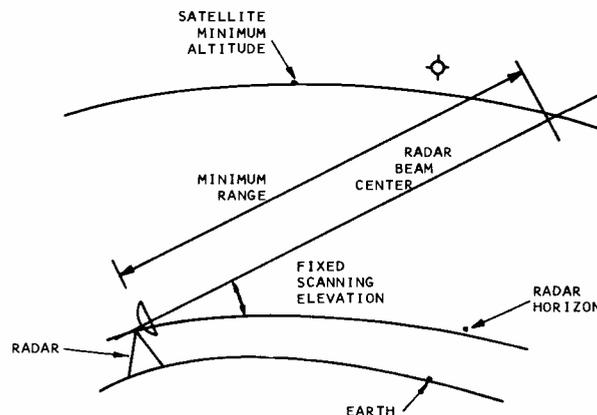


Fig. 2—Minimum satellite range.



of identity, if more than one prediction got through all the steps of the process, is determined by comparing the computed spatial separations of the candidates; the separation having the smallest magnitude is chosen. If only one candidate is available, its identity is applied to the actual measurement (Fig. 3). If no candidates survive the process, the observation is passed on to the final step in the classification process.

The final step in the classification process starts simply with a refinement of the first quality or preliminary filtering test. The first test examines the range of the object against a minimum range; below this, an observation could not have been a satellite. The refinement in this test concerns the earth model assumed. The former test assumes a spherical earth model while this test contains a more realistic oblate earth model. Such a test is considerably more complex from a computational standpoint. Preliminary filtering concludes with a data quality test. Basically, it is a test of the standard deviations of the range, azimuth and elevation parameter measurements. If the preliminary filtering tests are passed, the dynamic characteristics tests are performed.

The velocity and energy of the object are then computed from the observed parameters. To be a satellite, this computed velocity must lie between minimum orbital and escape velocity and the energy must be greater than that of an impacting body. If these criteria are satisfied, the observation is classed as that of an unknown object and is identified as such.

AUTOMATIC SATELLITE TRACKING

The quality of satellite observation data from a radar scanning a fixed elevation angle is a function of the time the space object is in the radar beam. The vertical or elevation dimension of the radar beam is several degrees but the horizontal or azimuth dimension scanned is quite large. An object having a large elevation rate would be expected to yield a relatively poor quality observation, while an object making a low-elevation-rate pass may yield fairly good data. Scan data, even when gathered under the most favorable circumstances, may not be good enough for some purposes. Specifically, better quality data is required for maintaining precise orbits on certain objects (notably payloads) and for readily establishing the orbital parameters of a new or unknown object. This quality of data is obtainable by tracking the object in question. What is perhaps even more important is the fact that tracking provides a series of position fixes over the whole period of time the object is within radar limits. When tracking an object, the radar no longer operates at a fixed elevation angle but can follow the object over a wide range of parameter variation.

Main considerations in developing the program's automatic satellite tracking capability were to provide considerable flexibility in determining what objects to track and an object-selection priority scheme; this feature is most necessary because of the possibility of having several objects to track at one time.

Three distinct, non-exclusive options

were found for determining what objects to track:

- 1) Permit specific known satellites to be identified as candidates for tracking at the time the time-ordered penetration predictions are prepared for the day;
- 2) Request the track of a known satellite by on-line card input of the object number; and
- 3) Allow automatic tracking of unknown objects.

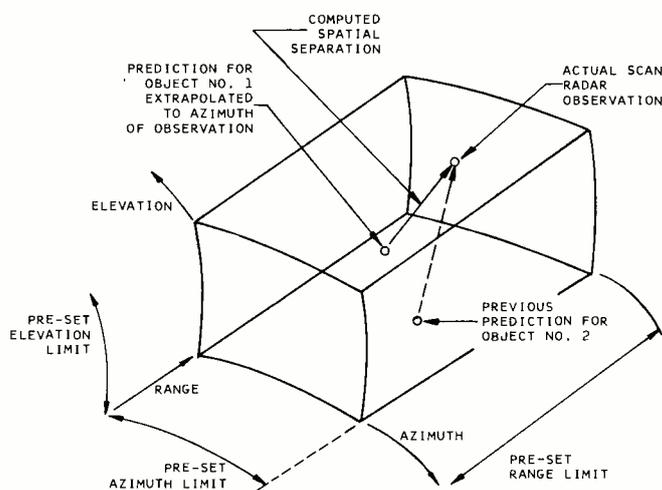
Most track requests are pre-planned by the SDC and can be entered into the system by option 1. Option 2 allows track requests to be entered at any time during a day's operation. Finally, option 3 permits acquisition of additional information on a suspected new or unknown object.

Automatic tracking is initiated only after a scan radar observation has been passed through the satellite discrimination process and found to be the known satellite for which a track request exists. Assuming that another track is not in progress, the scan radar observation is used to designate a position in space where the tracking radar may expect the object to be at this time. The tracking radar looks at the designated position and begins to track, if an object is there. Track data is consolidated into a single observation every ten seconds. The first of these ten-second, track-data sets is put through the satellite discrimination process to verify whether the object being tracked is the known or unknown object for which the automatic track was initiated. If the wrong object is being tracked, tracking is immediately terminated and the track information is discarded. If the proper object is being tracked, tracking continues until the object is no longer visible to the site and track-data sets are formed every ten seconds. These subsequent data sets are assumed to be from the proper object without the use of the discrimination process.

The previous discussion of target tracking assumed that no other track requests were in force during the time that the track was in progress. Such is not always the case; when a number of track requests are present, some arbitrary set of rules must exist if track information is to be obtained on the maximum number of objects. Such an object selection priority scheme was developed.

Two levels of priority were established. The higher priority was assigned to track requests resulting from scan-radar observations as opposed to continuing a track in progress. This choice assures that some track data will be ob-

Fig. 3—Observation identity selection.

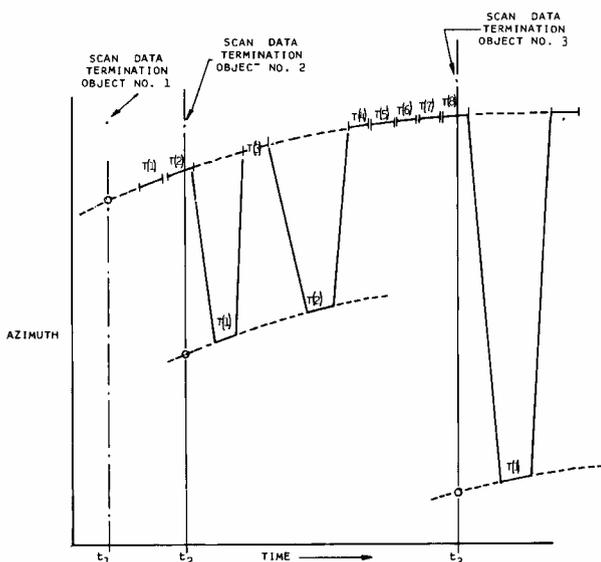


NOTE: DOPPLER AND TIME OMITTED FOR CLARITY

tained on all objects, if time permits. Conflicts arise within each of the priority levels; should two or more track requests be present, the object with the highest probability of being acquired for tracking is preferred. This acquisition probability is a function of the quality of the scan-radar observation; higher quality data gives a higher acquisition probability than low quality data.

Typical time-shared tracking occurring with the object selection priorities just described is shown in Fig. 4. For simplification, a single parameter (azimuth) versus time representation was chosen in Fig. 4. A scan-radar observation is discriminated as being object No. 1. The termination time for this particular piece of scan data is t_1 . It is determined that a track request has been entered for object No. 1 and, since no tracks are in progress, the tracking radar is designated and a track starts. $T(1)_1$ represents the first ten-second track on object No. 1. This data is subjected to the discrimination process, found to be object No. 1 and since no other requests are yet present in the system, the track is continued. At the conclusion of the ten-second track, $T(2)_1$, a higher priority request to track object No. 2 is present so that action is initiated. At the end of that track, $T(1)_2$, there are no other track requests present and since $T(2)_1$ is the oldest last piece of track data, object No. 1 gets another ten-second track. The track on object No. 2 cannot be resumed after $T(4)_1$ because it has left the site coverage in some parameter such as elevation, etc.

Fig. 4—Time-shared tracking.



SELECTED SATELLITE DATA TRANSMISSION

A real-time data link exists between the site and the SOC. If all observations were to be transmitted from all sites within the USAF SPACETRACK network to the SOC, the traffic would amount to nearly one-half million observations per month. This amount of information is neither necessary nor desirable to process at the SOC. As with track requests, the SOC pre-plans a list of satellites for which it wishes a particular site to transmit data. Normally these satellites are identified as candidates for data transmission at the time the time-ordered penetration predictions are prepared for the day. Transmission of data may also be varied by on-line card input of the object number.

Nine overall options for the transmission of satellite data have been specified by the SOC as are shown in Table I. All are presently implemented at the site and can be selected as operational use dictates. Data flow within the site's improved satellite information processing program is summarized in Fig. 5. Specific note is made of the sources of the various data shown in Table I.

CONCLUSION

Introduction of the modified program has resulted in marked improvements in four major areas:

- 1) Availability of satellite information processing was doubled.
- 2) Satellite discrimination efficiency has been improved.
- 3) The limited tracking capability was

replaced by a comprehensive satellite tracking facility.

- 4) The selective transmission feature has permitted more efficient use of the data transmission equipment and terminal (SOC) facilities.

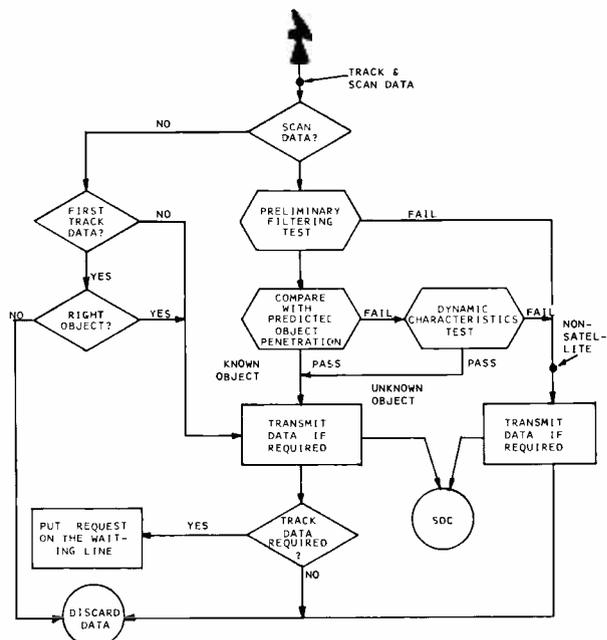
ACKNOWLEDGMENTS

The writers would like to gratefully acknowledge the efforts of Mr. W. J. McCready, RCA-DEP, who implemented the tracking logic changes necessary to accomplish the automatic satellite tracking features of the program; and Mr. I. Morton, RCA-GB Ltd., who developed the mathematical formulation for the dynamic characteristics test.

TABLE I—SATELLITE DATA TRANSMISSION OPTIONS

Options	Descriptions
1	No Transmission
2	All known satellites
3	Selected known satellites
4	All unknown observations Non-satellites No identification attempted Unknown satellites
5	Unknown satellites
6	All observations Non-satellites Known satellites No identification attempted Unknown satellites
7	All satellites Known satellites Unknown satellites
8	All unknown observations and selected known satellites Non-satellites Selected known satellites No identification attempted Unknown satellites
9	Unknown satellites and selected known satellites Selected known satellites Unknown satellites

Fig. 5—Site program data flow.



TWO-POLARIZATION FM BROADCASTING WITH A SINGLE ANTENNA

To provide better FM service for the automobile radio listener, the FCC permits FM stations to transmit a vertically polarized signal in addition to the standard horizontally polarized signal. Many stations have provided this service by adding a second antenna system for the vertically polarized signal. For applications where a totally new antenna system is desired, RCA has developed a new transmitting antenna which simultaneously radiates both horizontally and vertically polarized signals from a single set of radiators. In this paper the antenna is described, its characteristics examined, and its application discussed.

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THE Type BFC circularly polarized FM broadcast antenna has been developed to provide the dual polarization necessary for improved reception of FM broadcasts by automobile and other FM radios employing vertical whips or other antennas not necessarily best oriented to receive horizontally polarized signals.

Until now, this increasing need has been met by adding a separate vertically polarized transmitting antenna to supplement the traditional horizontally polarized antenna system. The new FM transmitting antenna, however, results in only half the weight and wind loading of a combination system for the same service, and reduces installation costs. Moreover, the antenna offers an opportunity to either double the total transmitted power or double the antenna aperture, or gain per polarization, without exceeding the licensed maximums, and thus provides increased total broadcast service.

The antenna uses a radiating element made of two dipoles curved into one-turn helices, and mounted in interlaced position resembling the threads in a double-threaded screw. The dipoles are welded onto a mechanical supporting member, providing a rugged and simple element that radiates circularly polarized signals omnidirectionally. Various gains are obtained by stacking these elements approximately at one wavelength spacings.

BENEFITS OF DUAL POLARIZATION

The ordinary whip antenna for car and portable radios does a commendable job

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of pulling in AM stations. It is fundamentally a vertically polarized antenna, however, and tends to operate poorly in receiving horizontally polarized waves, such as FM broadcasts. Obviously, if the transmitted field was purely horizontally polarized and the whip antenna, in the case of the auto, was perfectly vertical and centered on the auto roof to provide a symmetrical ground plane, no reception would take place. Thus, it may be said that FM broadcast reception in automobiles using vertical antennas to a great extent results from "discrepancies" and is therefore somewhat unreliable; thus, dual polarization in FM transmission is desirable.

ACHIEVING DUAL POLARIZATION

Dual polarization can be achieved by employing two separate antennas, one for transmitting the horizontally polarized signal and another for the vertically polarized signal. Although effective, this method may prove to be complex and expensive; it may also be impractical in some cases where the existing tower structure may be incapable of supporting the additional weight and wind load. There was the need, therefore, for a single compact antenna to radiate a vertically polarized signal in addition to the horizontally polarized signal, both signals for omnidirectional service and at equal power levels.

To meet the requirements for omnidirectional service and provide broadcasters with a simple, rugged and economical FM broadcast antenna, RCA developed and is now producing the

BFC series of antennas. Using a single radiator, these antennas radiate the signal in two polarizations in the form of a circularly polarized signal to serve home, portable, and car radios.

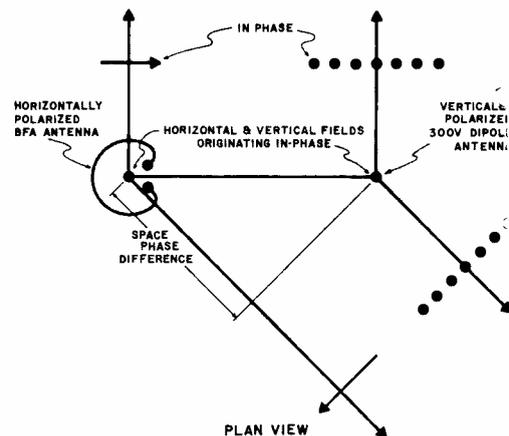
SOME ADVANTAGES OF CIRCULAR POLARIZATION

The principal advantage of circularly polarized transmission is that the rotating field provides reception with any logical orientation of a linear receiving antenna. It may not seem important, but in designing a single antenna to radiate half the power horizontally polarized and half vertically polarized, a predetermined fixed phase between the two radiated signals is desirable. This is an extremely desirable characteristic that is seldom obtained in separate radiating systems.

Of course, if pure vertically and pure horizontally polarized receiving antennas are used and propagation does not de-polarize the signals, the phase relationship does not matter; in such cases, the receiving antennas are totally "blind" to the other polarization and thus receive only one. However, receiving antennas such as automobile whips, cord antennas and even built-in antennas vary greatly in polarization and thus receive both signals, so phase may become important.

Performance characteristics of typical dual systems are exemplified in Fig. 1. If polarization is observed in various azimuthal directions, it may be noticed that a range of phase relationships is obtained due to space phase variation. If the spacing between the phase centers is a half wavelength or more, any phase difference between the two polarizations will result. In practice, the spacing has

Fig. 1—Phase relationships between signals radiated by separate horizontally and vertically polarized antennas illustrated in two directions.



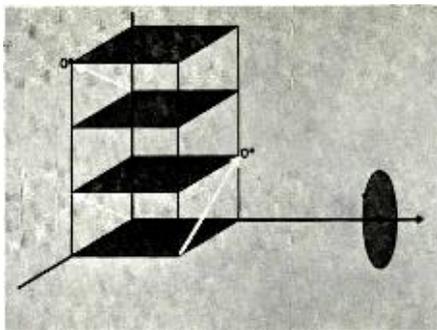


Fig. 3—Current elements (separated by a quarter wavelength) rotated and shifted in their respective planes still result in circularly polarized radiation in one direction.

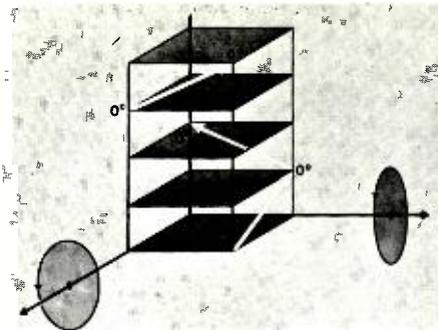


Fig. 4—Two current element pairs are arranged to form a single-turn helix. By adding the second current element pair, in the same phase, a circularly polarized signal in all azimuth directions is obtained.

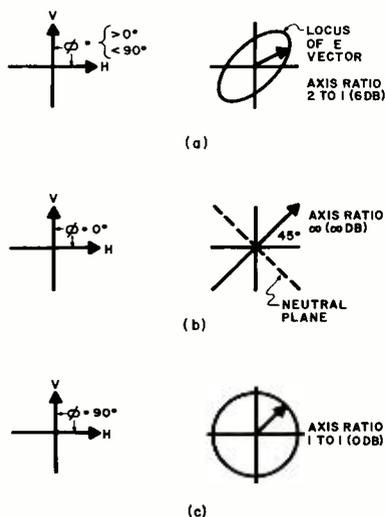


Fig. 5—Two resonant half-wave dipoles are curved into one-turn helices and interlaced to maintain constant current for omnidirectional service.

generally been kept below a quarter wavelength to reduce the overall range of phase variation. However, varying phase differences do exist in present installations.

When the two orthogonally polarized signals with equal power fed into each polarization are examined together, three categories of signal may be obtained (Fig. 2). The most common is the case when the two signals have some oblique phase angle between them and the resultant field vector thus traces an elliptical figure which never touches the origin (Fig. 2a). This is called elliptically polarized signal. A characteristic of this signal is that a linear receiving antenna approximately perpendicular to the path of the wave propagation always extracts some energy from the field regardless of the angular orientation of the antenna. The amount, however, varies and the ratio of maximum to minimum field is expressed by the polarization axis ratio. This is the ratio of major and minor axes of the polarization ellipse. The ratio is not unity even though the same energy is radiated both

Fig. 2—Total fields produced by two orthogonal signals for elliptical polarization (a), linear polarization (b), and circular polarization (c).



in horizontally and vertically polarized components.

A special case is obtained when the two signals are in phase (Fig. 2b), then the ellipse reduces to a straight line and a 45° linearly polarized signal results. In this case, if the receiving antenna happens to be polarized at the other 45° direction, no signal will be received.

A circularly polarized resultant occurs when the two waves are in phase quadrature (Fig. 2c). In this case, a linearly polarized receiving antenna extracts a constant power from the field, whatever the receiving antenna orientation, as long as it is perpendicular to the direction of the wave propagation.

Since 45° polarization theoretically provides a chance of no reception, circular polarization was chosen for the RCA design to provide reception with linear antennas regardless of their orientation. Further, circular polarization is more closely related to elliptical polarization which exhibits no undesirable characteristics.

OPERATING PRINCIPLES

The evolution of the circularly polarized radiating element may be shown with very simple models. As previously described, two orthogonal signals, such as vertically and horizontally polarized signals, when in phase quadrature produce a circularly polarized field. These two fields may be produced by two orthogonal current elements in the same plane. However, phase quadrature may also be produced if two in-phase current elements are separated by a quarter wavelength. This results in a 90° phase difference between the two fields.

If the current elements of this pair are each rotated and shifted in their respective planes (Fig. 3), circular polarization is still maintained in a direction perpendicular to both elements. By adding another current element pair as in Fig. 4, a model of a single turn helix

will radiate principally broadside and with circular polarization to all azimuthal directions when the helix periphery, $C\lambda = \sqrt{2S\lambda}$ and the turn length, $L\lambda = 0.5$, where $S\lambda$ is the spacing between turns. (All parameters are in λ .)

As can be seen, this type of helix has a small diameter in terms of wavelength. This mode of operation from helices is relatively unknown. The commonly used modes are the end-fire and the reflector-induced, side-fire modes of large diameter helices.

To employ the principle described, a constant in-phase current had to be produced. The in-phase current was obtained by employing a resonant half-wave dipole. However, the current distribution along the dipole is approximately sinusoidal, and to obtain constant enough current around the periphery to result in an omnidirectional horizontal radiation pattern, the dipole would have to form about a two-turn helix of approximately $\lambda/10$ (or 1-ft diameter). Such a small diameter, though mechanically desirable, would have resulted in a quite small volume with relatively narrow bandwidth capabilities. Hence, a larger diameter of about 0.15λ was chosen and two dipoles employed to obtain a constant current. The dipoles were each curved into a one-turn helix and interlaced as shown in Fig. 5. The sum of the currents on the two dipoles, in phase, is approximately constant around, and thus, an omnidirectional pattern is obtained.

RUGGEDNESS AND SIMPLICITY

The characteristic voltage zero in the middle of a resonant dipole provides an excellent point for good mechanical support. Thus, a 1 3/8-inch diameter "backbone" was designed and the centers of the dipoles were heliarc welded onto this support for rugged construction.

The most convenient feed system for the antenna was, of course, a coaxial

line. By shunt feeding from a $3\frac{1}{8}$ -inch line, an unbalanced feed point with a single end-seal was obtained. This is the only insulator in the antenna. To accommodate the unbalanced feed and to provide flexibility of adjustment, shunt feed in modified delta-match form resulted in a simple, rugged radiating element, which is doubly supported by the heavy-wall $3\frac{1}{8}$ -inch transmission line.

ELECTRICAL PERFORMANCE CHARACTERISTICS

Horizontal patterns of the radiating elements in free space are essentially omnidirectional for both polarizations (Figs. 6 and 7). The best circularity will be obtained with pole-mounted antennas installed on top of a tower or building. For a side-mounted array, the extent of deviation from a circular pattern is dependent on the type and size of the tower. The shape of the vertical patterns for each polarization is determined by the number of layers, magnitude of illuminating currents and their phases, and possible tower effects. Null fill and/or beam tilt is possible.

Although the vertical patterns derive in the conventional manner, principally from the aperture or number of layers, the gain of the BFC-series antennas is about half a unit per wavelength, because the power is equally divided between the horizontally and vertically polarized components. The antennas are built as types BFC-1 to BFC-16, consisting of 1 to 16 stacked layers. Spacing between layers is approximately one wavelength and the power gains are from 0.46 to 8.9 respectively for both polarizations.

The BFC-series is designed for single-channel operation. However, since dipoles are employed as the basic elements, relatively low circulating currents exist,

resulting in a rather broadband element covering some 2 MHz within a vswr of ~ 1.3 . Each array is equipped with a variable transformer at the input, thus facilitating a simple vswr field adjustment to below 1.1 across the channel in question. Such a low vswr assures excellent performance and meets the most demanding requirements. The low circulating currents due to dipole principle, also result in low voltage gradients and thus the high power rating of 10 kW per element. When several layers are utilized, the total rating, however, may be limited by the capability of the $3\frac{1}{8}$ -inch transmission line to a very adequate 40 kW.

The polarization axis ratio of an element in free space is about 1.5 dB and a maximum of about 4 dB around the periphery at the horizontal direction. These values represent a good circularly polarized signal to reduce the chances of "no-signal" with randomly polarized receiving antennas.

MECHANICAL CHARACTERISTICS

The BFC design will withstand wind loads of up to 50/33 psf. Both the weight and wind loading of BFC antennas is only about half that of combination antennas for two polarization transmission. Further economies are realized because of the simpler installation of the BFC.

For environmental protection, good materials are used throughout. The radiator is stainless steel which assures that no corrosion or electrolysis will take place. The end seal is constructed of ceramic, which tends to stay cleaner than other insulating materials, assuring long trouble-free operation.

The large feed systems which are pressurized all the way to the end seals assure reliable operation. BFC antennas with up to seven layers are end-fed. An-

tennas employing eight or more layers are fed at the center of the array through a tee. Since both horizontally and vertically polarized signals are radiated by one set of radiators, no external power splitters are needed as in the combination antenna systems.

CONCLUSION

The circularly polarized BFC antenna was developed to meet the need for a simple, rugged, and economical FM broadcast transmitting antenna, capable of radiating simultaneously both horizontally and vertically polarized signals. Designed for omnidirectional service, the BFC may be pole mounted on top of a tower or building, or sidemounted on a tower. It combines excellent electrical and mechanical characteristics with low wind loading and weight, and provides for economy of installation. The antenna is in use by FM stations in Los Angeles and Philadelphia.

Fig. 6—Horizontal pattern of the horizontally polarized signal component in free space.

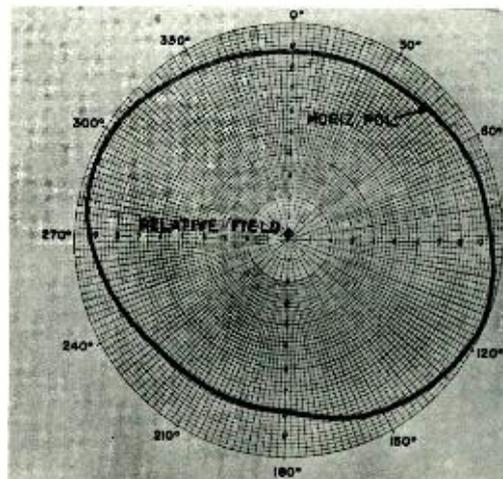
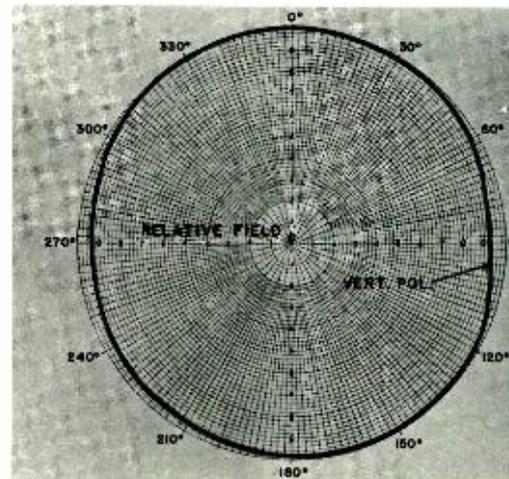


Fig. 7—Horizontal pattern of the vertically polarized signal component in free space.



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Finnish Broadcasting Corp. to work mainly on AM and FM transmitters and antennas. He also acted as Technical Advisor for the Finnish Government and the City of Helsinki on VHF communications equipment. In 1952 Dr. Siukola joined RCA as a design and development engineer on television transmitting antennas. He has continued in this field and is presently technical consultant to the TV Antenna Engineering section and leader of the Advanced Development group. He has been instrumental in developments familiar to the TV Broadcast Industry, such as: high-gain Superturbo-stile antennas, Traveling Wave antennas, Zig-Zag antennas, "Candelabra" installations, and RF pulse analysis of antenna system performance. Dr. Siukola who is listed in the American Men of Science, has presented and published several papers in his field. He is a member of IEEE, the Professional Group on Antennas and Propagation, Professional Group on Management, Institution of Electrical Engineers, England, Franklin Institute, Phi Kappa Phi, Eta Kappa Nu, and Pi Mu Epsilon.

A COMPUTER PROGRAM FOR ANALYZING ALTERNATIVE MAINTENANCE POLICIES



WENDELL A. TRIPLETT received the BSEE with high honors from Ohio University in 1950, and the MSEE from the Drexel Institute of Technology in 1955. His first six years in engineering included research on solid state devices, instructing of field engineers in electronic equipment, and the design of automatic test equipment for the Sidewinder missile. Mr. Triplett joined RCA in 1956 as a Project Engineer in the Missile & Surface Radar Division, where he conceived and developed system simulations and tests for the Talos Land Based System and BMEWS. In the Major Systems Division from 1961 to 1963, he functioned in a project management role in the acquisition of new business, including the LEM project. Since joining SEER in September 1963, he has concentrated on the analysis of satellite vulnerability, anti-jam satellite communications and support systems.

A computer program called CO-AMP I (cost optimization and analysis of maintenance policies) has been developed in SEER. Written in Fortran IV for the 7090 computer, CO-AMP I enables a rapid analysis and evaluation of alternative maintenance policies for electronic equipment. Due to the increased emphasis by the military on minimization of operational support cost, it is not only timely that such an analysis tool has been developed, but it is also imperative that this technique be continually improved. This paper presents the purpose of the analysis tool, a brief description of the mathematical model programmed, results of its applications, and improvements currently underway.

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THE purpose in formulating CO-AMP I was to provide a rapid and efficient analysis tool in performing trade-offs among the many alternative concepts available for maintenance/logistic support of electronic equipment. Some of the important determinations are:

- 1) least-cost support concepts for the electronic portions of military weapon systems.
- 2) optimum module sizes (circuits per module) for various support concepts.
- 3) most-cost-effective maintenance level for automatic checkout (i.e., built-in versus separate automatic test equipment).
- 4) conditions under which a discard policy becomes economically feasible.
- 5) least-cost maintenance policy as a function of such factors as operational reliability, utilization rate, and deployment.

DESCRIPTION OF COMPUTERIZED MODEL

An analytic cost model was formulated to analyze alternate policies of providing maintenance support for electronic equipment. Utilizing this model, a computer program was written to 1) accept 45 input parameters related to equipment cost, utilization, deployment, test, repair, failure, life, structure, etc.; and 2) compute annual maintenance support costs for manpower, test equipment and procedures, inventory, administration, shipping, and consumed items for up to six maintenance policies in one computer run. Also computed are the annual cost associated with the prime equipment and the grand total annual cost.

The grand total maintenance support costs are logically divided by the model, as shown in Fig. 1, into seven major

cost factors: cost of prime equipment (CPE); cost of test or troubleshooting equipment (CTS); cost of inventory support (CIV); cost of maintenance manpower (CMP); cost of supply administration (CSA); cost of transportation, packaging, and shipping (CSH); and cost of piece part supplies (CPP). The first two are fixed costs and the last five are variable. These variable factors relate to the logistics, logistics management, and manpower required on an annual basis to provide maintenance support.

The **prime equipment** (CPE) considered in the model is specifically that electronic equipment whose purpose is to perform a function in support of a system mission. Since a prime equipment is a fixed initial investment, its cost is prorated over its lifetime or over the length of the program, whichever is shorter, to obtain a yearly assessment.

The **test and troubleshooting equipment** (CTS) considered in the model is that equipment utilized to 1) detect the presence of a fault in the prime equipment; 2) isolate faults to a specific equipment level (assembly, module, piece part); and 3) check out faulty equipment which has been restored, presumably to working condition. The cost for test equipment is included at the organization, base, and depot maintenance levels. Since test equipment costs are or can be considered as one-time initial costs, they are prorated to obtain a yearly assessment over the life of the test equipment by the same rule used for CPE.

Inventory support (CIV) provides the spare items required to replace and repair failed units of prime equipment at each of the various support installations. The spare items in the model include modules, functional assemblies, or sets

depending on the level of sparing or repair policy under consideration.

The total annual cost of inventory support is a function of the number of operational support bases in the system, the annual cost of safety stock at a base, the annual cost for active stock at a base, the annual cost of consumed stock at a base (particularly important when considering throw-away), and the annual costs incurred in reordering spares for a base.

Maintenance manpower (CMP) provides the capability required to perform all manual maintenance support functions. The annual cost of maintenance manpower in the model is a function of the number of bases in the system, the annual demand for maintenance actions, the efficiency of the available maintenance manpower, the cost of manpower, and the man hours required to perform the necessary maintenance operations. Manpower costs at a base are characterized by an annual cost of providing a trained maintenance technician. This cost can be interpreted as including the prorated cost of his training, experience, skill, and any other factors appropriate to the system under analysis. Manpower costs at a depot are characterized by an hourly repair cost.

Supply administration (CSA) accounts for the total annual cost of supply administration; it is a function of the cost of entering a new item into the military supply line and the yearly cost of maintaining it. The cost of initial entry is prorated over the life of the system utilizing the equipment.

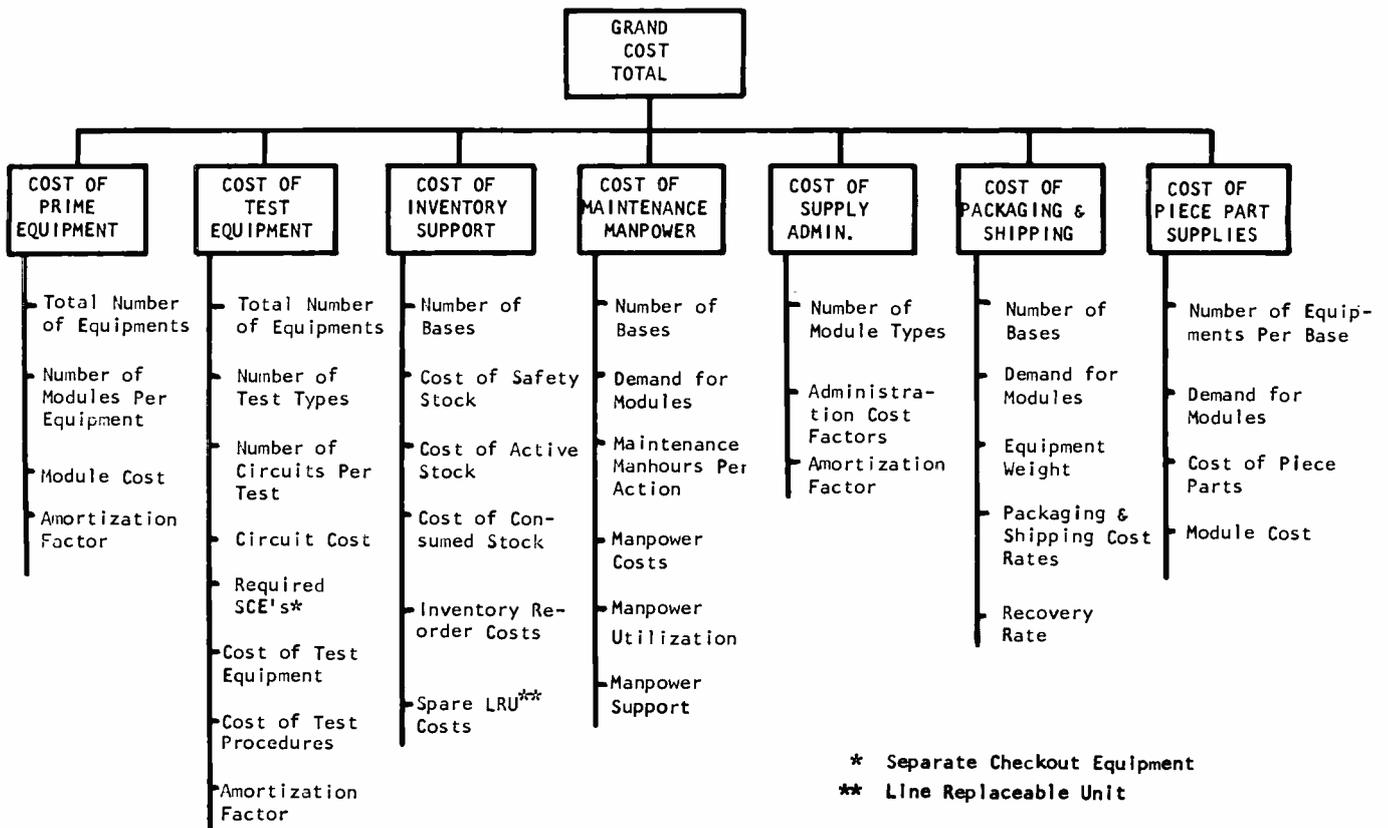


Fig. 1—Major factors contributing to maintenance support costs.

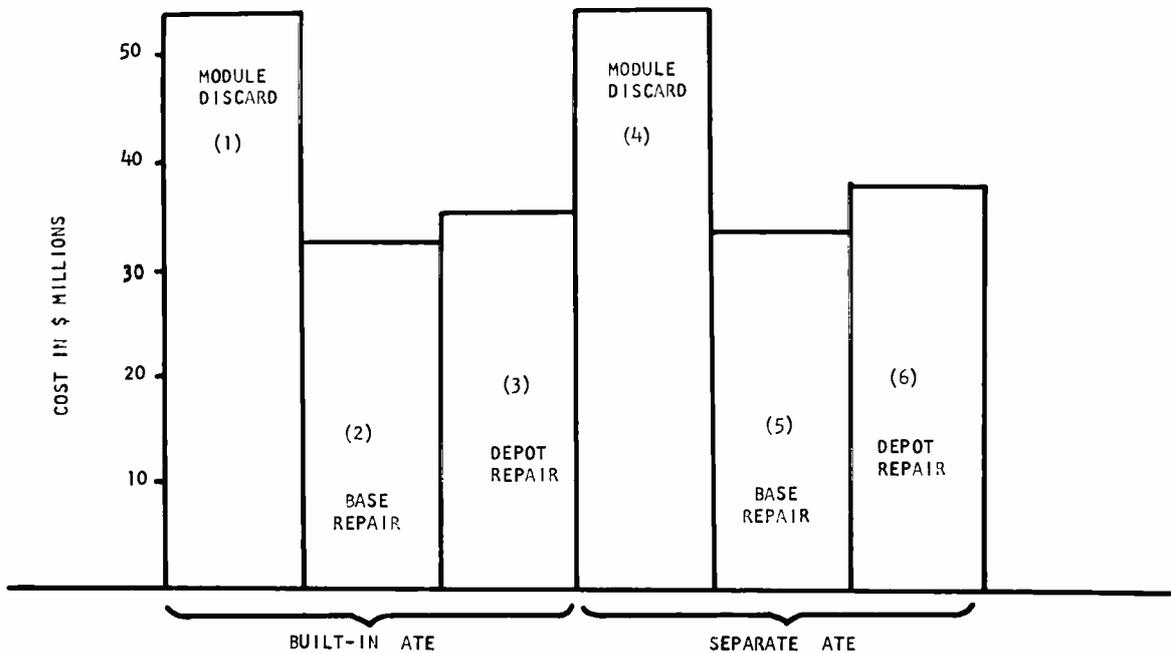


Fig. 2—Total annual cost for different SAM-D maintenance policies.

Transportation and shipping (CSH) provides for the flow of replacement stocks and repaired items from the depot to the bases and failed items from the base to the depot. The cost of packaging and transportation is a function of the number of bases in the system, the demand for spares at each base, the weight of the items to be shipped, and the shipping cost per trip between base and depot.

Piece part supplies (CPP) provides the material for repairing failed modules. The cost of piece part supplies consumed in the repair operation is assumed to be proportional to the number of repairs made (the demand), the cost of a basic circuit, and a factor which allocates a percentage of the cost of a basic circuit to each piece part repair.

In summary, the computer calculates the following general equation:

$$GCT = d(CPE) + d(CTS) + CIV + \\ CMP + CSA + CSH + CPP$$

where:

GCT = grand cost total of prime equipment and maintenance support annual costs.

d = a pro rata factor to annualize the cost of prime and test equipment.

CPE = cost of prime equipment.

CTS = cost of test equipment.

CIV = annual cost of inventory support.

CMP = annual cost of maintenance manpower.

CSA = annual cost of supply administration.

CSH = annual cost of transportation, packaging and other shipping charges.

CPP = annual cost of piece part supplies consumed in the repair activity.

The computer calculates approximately 38 basic expressions and formulates the sum in accordance with the above generalized expression.

APPLICATION RESULTS

The CO-AMP program to date has been used in analyzing maintenance policies for SAM-D, AAFSS (Advanced Aerial Fire Support System), and the improved ARC-34 communications set.

In the case of SAM-D, three alternative maintenance policies were investigated at the module level: (1) discard faulty modules, (2) repair faulty module in field, (3) repair faulty module at depot. These three are applicable to failure detection either by built-in automatic test equipment (ATE) or by a separate ATE located at the battalion (to accept faulty drawers or functional units for subsequent fault isolation to the module level). Let alternates (1), (2) and (3) be used for the built-in ATE, and let them

be renumbered (4), (5) and (6) for the separate ATE, as shown in Fig. 2.

Fig. 2 summarizes the results obtained in the analysis based on a representative field army deployment of SAM-D. It is seen that policy (2), automatic built-in test down to the module level and field repair, is the lowest cost approach. However, policy 5, separate automatic test at the battalion level of functional units or drawers down to the module level and attendant module repair in the field, is a very close competitor.

A sensitivity analysis was performed for SAM-D maintenance policies by varying 13 different program input parameters over a range of two octaves about the center value. Ordering of maintenance policies with regard to cost was not altered over the ranges examined in the sensitivity analysis, substantiating the earlier findings.

The AAFSS is a high performance helicopter containing 21 avionic subsystems. The mission is characterized by an extensive forward area deployment. Initial results obtained through use of the CO-AMP program are shown in Fig. 3. The maintenance policies analyzed were the same six outlined for SAM-D above, plus a manual test equipment fault isolation policy for two different assumed maintenance personnel skill levels. Maintenance policy (5) which utilizes separate automatic test equipment and field repair has the lowest cost, closely followed by the manual policy for skill level 1. Policy (5) has an additional advantage over the manual approach in that fewer skilled maintenance personnel are required.

For the improved ARC-34 communications set, seven different alternative maintenance policies were analyzed, these included:

- 1) Send the faulty *R/T* back to depot for repair.
- 2) Fault isolate to the functional assembly at the base and repair the functional assembly at the depot.
- 3) Fault isolate to the piece part and repair at the base.
- 4) Fault isolate to the module at the base and repair the module at the depot.
- 5) Fault isolate to the functional assembly and throw the functional assembly away at the base.
- 6) Fault isolate to the module and throw the module away at the base.
- 7) Throw the faulty set or *R/T* away at the base.

Nine separate sensitivity analyses were performed for each policy to determine intervals of dominance and cross-over points. The results of two of the sensitivity analysis are presented in Figs. 4 and 5. Fig. 4 is the variation of support

cost with set utilization rate, and Fig. 5 presents the variation of cost with set reliability. The ordinate is support cost expressed as a percent of the total prime equipment cost. In the terminology given under the model description

$$y = \frac{d(CTS) + CIV + CMP + CSA + CSH + CPP}{d(CPE)}$$

For a set utilization rate of 4.4% (Fig. 4) and an MTBF of 5640 hours (Fig. 5), policy I—depot repair of the *R/T* to the piece part level with no repair at base—is the dominant choice. These figures also indicate that policy I is far superior to the other policies at set utilization rates up to 50% and over all values of MTBF shown.

PROGRAM IMPROVEMENTS

Based on the experience of using CO-AMP 1 and additional learning in the areas of support system costs, a new program called CO-AMP 2 is under development. This new program will allow the evaluation of up to 20 different maintenance policy variations for a weapon system. Some of the salient features being incorporated in this program are:

- 1) Provisions for inclusion of development, acquisition, and replenishment costs for a system.
- 2) Inclusion, of logistic pipe-line effects with regard to cost and trade-offs between policies.
- 3) Increased flexibility in the input data requirements for the computer program.
- 4) Additional levels of maintenance, which will include equipment, organization, intermediate, and depot.
- 5) Improved treatment of the determination of safety stock (or back-up spares) through the incorporation of refined lead time computations.

ACKNOWLEDGEMENTS

Although the original CO-AMP 1 program was formulated by the author, with important assistance from a textbook called "Maintainability" written by Goldman and Slattery, much of the analysis of weapon systems and equipment and major improvements (i.e., CO-AMP 2) to the original program have been carried out by other people. For example, B. Cola performed the SAM-D maintenance analysis and A. Messey is carrying out the AAFSS work. W. E. Rapp has been a major contributor in formulating CO-AMP 2 with heavy assistance from A. Messey in the area of program organization and implementation.

The author also wishes to express his thanks to the ASD-Burlington ATE PMO, for their support and encouragement in carrying out the work described herein.

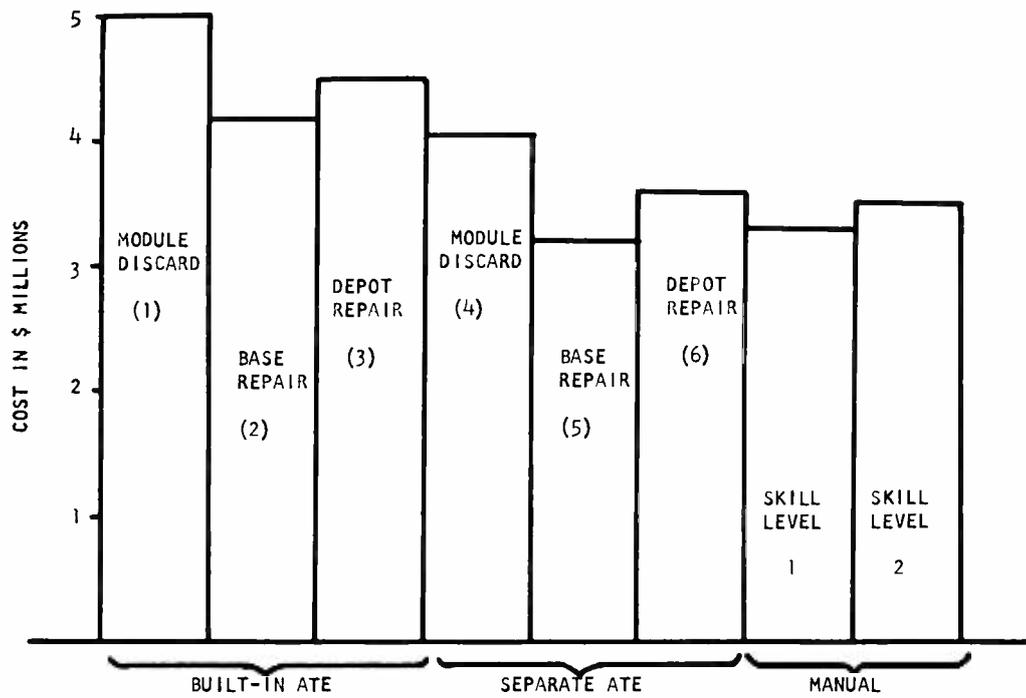


Fig. 3—Total annual cost for different AAFSS maintenance policies.

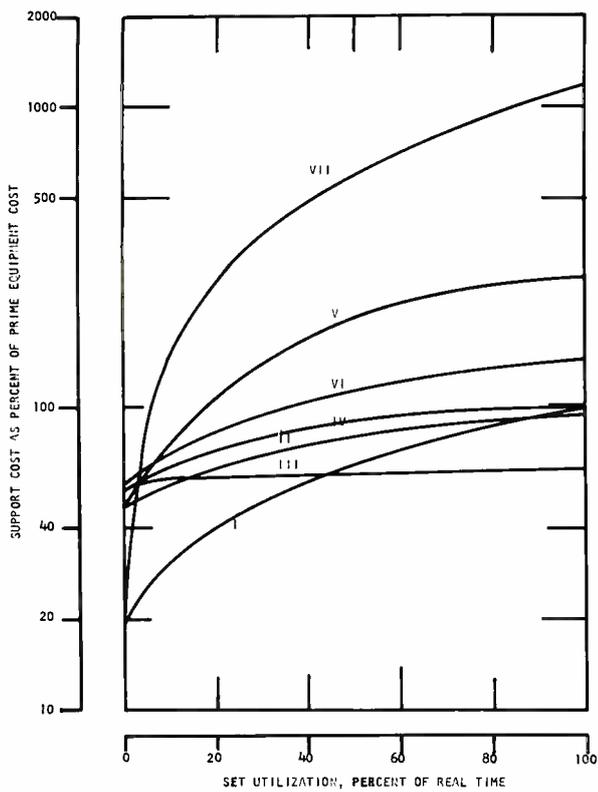


Fig. 4—Support cost versus set utilization rate.

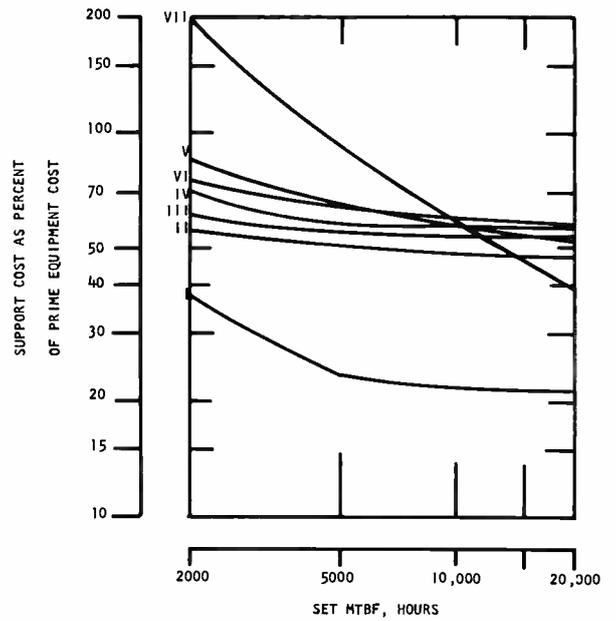


Fig. 5—Support cost versus set MTBF.

AN ADVANCED TECHNIQUE FOR VIDEO DATA COMPRESSION

A new video digital data compression technique, Time-Buffered Coarse-Fine (TB CF), is presented along with experimental results. High-quality video pictures can be produced using this technique with compression ratios, referenced to 6-bit Pulse Code Modulation (PCM), from 2:1 to greater than 20:1 depending on the subject complexity and the element accuracy required, with a typical compression ratio of 6:1. This system uses a modified version of the Coarse-Fine Compressor invented and implemented by the authors in 1964 with additional processing of the data by noise-pattern class recognition and removal circuitry and run-length coding. The Coarse-Fine system is discussed briefly followed by a detailed description of the operation of the Time-Buffered Coarse-Fine system. Time-Buffered Coarse-Fine compressed pictures are then presented and analyzed.

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SINCE 1963, RCA Astro-Electronics Division has been engaged in R & D studies concerning the compression of video data to reduce transmission bandwidth. These studies have led to the invention, fabrication, and evaluation of three new data compression techniques: the Improved Gray Scale PCM¹ which yields a 3:1, 2:1, or 1.5:1 compression over 6-bit PCM, depending on the processing setting selected; the Coarse-Fine PCM¹ which gives a 2:1 compression with high element fidelity; and the Time-Buffered Coarse-Fine Advanced Data Compressor which yields compression ratios from 2:1 to greater than 20:1 with 6:1 typical.

Data compression is possible because most pictures contain redundant data which need not be transmitted to extract the unique information. Most data compression techniques eliminate or utilize this redundancy to reproduce the vital information at the receiver while transmitting a reduced amount of data. Two classes of data compression techniques exist: constant compression techniques in which a reduced but fixed number of bits are transmitted for each sample or picture element, and time-buffering techniques where either the compression obtained depends on the statistics of the picture or where a one-to-one correspondence between picture elements in the original picture and the compressed data stream does not exist. Various analyses of the amount of redundancy generally encountered in pictorial information have indicated that compression ratios of about 2:1 over 6-bit PCM (effectively 3-bits per picture element) can be obtained using non-time-buffering (constant compression) techniques while reproducing the pictures with reasonable fidelity. Time-

buffering offers various amounts of reduction dependent upon the complexity of the pictures involved.

Six-bit PCM, which yields 64 intensity levels, is chosen as a standard since it produces a picture essentially indistinguishable from the original analog. If fewer than six bits per picture element are used, not only does the accuracy of the picture decrease, but a contouring effect becomes noticeable.

COARSE-FINE DATA COMPRESSOR

Properties

The Coarse-Fine system, an important part of the overall time-buffered compressor, is a non-time-buffering technique which gives a constant compression of 2:1 over 6-bit PCM while providing a high picture element accuracy. For pictures of average complexity, between 80 and 90 percent of the picture elements are reproduced to 6-bit accuracy and the remaining elements are reproduced to 3-bit accuracy, with the accuracy of each element identifiable.

In the Coarse-Fine system, the original signal is digitized to six bits and either the three most-significant bits (coarse information) or the three least-significant bits (fine information) are transmitted. If the original signal is varying extremely rapidly over a range greater than one-eighth of full scale such

that there is a change in the three most-significant bits at each sample (or picture element), three bits per element are transmitted and displayed as "absolute" levels. However, if the signal is varying such that for four or more successive samples the three most-significant bits do not change, the three least-significant bits are transmitted and displayed as "relative" levels with respect to the most recently received coarse level. An interword coding technique is used to convey to the receiver the Coarse-Fine status changes and hence it is not necessary to consume light levels or add words for signalling. A three-word memory is required at each end of the transmission link and three successive words are compared at all times.

Near-Perfect Pictures

The Coarse-Fine system can be augmented to produce a near-perfect picture by a technique called "Coarse Element Refinement," which is accomplished by sending the fine information for those element positions transmitted in the coarse mode. This added data will decrease the compression ratio somewhat below the 2:1 value, yielding a compression ratio of approximately 1.8:1 for a picture of average complexity; however, the reproduced picture is almost exactly the same as the original, the maximum error being 1/64 of full scale for a small percentage of the elements.

TIME-BUFFERED COARSE-FINE COMPRESSOR

Philosophy

The Coarse-Fine system provides a constant non-statistical compression ratio
Final manuscript received October 19, 1966.

of 2:1 with respect to 6-bit PCM. The constancy of this compression ratio on an element-to-element basis is a significant advantage since with a prior knowledge of the compression ratio the storage requirements and net data yield of any system are known fixed quantities and no special buffer storage equipment is required at either the transmitter or receiver. Constant compression techniques providing compression ratios greater than 2:1 produce significant deterioration in the reproduction; therefore, further effort was directed toward time-buffering techniques. The large content (80 percent or more) of fine-level signals in a typical CF coded video signal immediately suggests the development of a redundancy removal technique operating within the CF code but only on fine elements. The realization of this Time-Buffered Coarse-Fine technique involved the solution of two principal problems: the transmitter must contain hardware to define and identify redundant element occurrences; and the occurrence and number of element removals in the processed data stream must be conveyed in that stream to the receiving decoder.

As a starting point in examining the redundant element removal (RER) coding approach selected, the redundant element identification logic (yet to be described) will be assumed to be producing successive redundant element identifications which are three to an infinite number of elements in length. A redundant element identification is never produced if it will persist for less than three elements.

The RER signalling logic, having received a redundant element identification, defines the first element light level as the run light level. The occurrence of the beginning of an element removal run is then conveyed to the receiver by altering (if necessary) the second element so that it is identical to the first. The TB CF decoder accepts two successive identical fine words as indicating the beginning of a redundant element removal run. The run light level is identified by the value of these words. Conflicting occurrences in non-redundant fine levels (i.e., two words identical but the third unacceptable) are removed in the identification logic by inverting the least significant bit of the second word. The identification logic must operate on the traffic for redundancy determination *after* conflicts have been removed.

The number of removed element positions is conveyed to the receiving decoder by the signalling logic as a composite signal of 3-bit words subse-

quent to the run start indicator. N_c , the number of members in the composite required to describe a run of length R (including the two level indicating words) satisfies the inequality:

$$3 + \log_3 \left(\frac{R+2}{4} \right) > N_c \text{ (integer)} \geq 2 + \log_3 \left(\frac{R+2}{4} \right)$$

where $R \geq 3$. A composite signal was selected because with such an approach the number of bits required to convey the length of a run decreases as the run length decreases.

Having determined an efficient technique for the conveyance of run-length duration signals, attention can now be directed to the development of a method for identifying signal occurrences which will be accepted as redundant. At least two approaches are possible in that either acceptable information signals or suppressible noise occurrences could be defined. The second alternative approach, that of defining noise, was selected because it offers several advantages. The statistical nature of the noise and its functional dependencies on such parameters as signal amplitude, time, temperature, etc., are known or determinable. The correlation time, i.e., the amount of past history which affects the present, is small and consequently a minimal number of elements must be examined to identify probable noise occurrences. The most important advantage of the noise definition approach, which is called noise pattern class recognition and removal, results from the fact that the great majority of noise occurrences are small in amplitude; consequently, the occasional erroneous suppression of a signal occurrence as noise will not result in a large light error. The experimental system applies various tests to the data stream allowing the continuation of a run until any one or more of the test constraints are violated. The types of tests conducted and constraints applied are discussed in the following paragraphs.

Run Start Test: A run start was made dependent on the relative values of three successive elements present within a small data storage shift register. The run level, when a run was identified, was made equal to the non-conflicting value of the first of these elements. The 3-element relation tests may be thought of as amplitude apertures. The equipment allowed the selection of one of three apertures: narrow, medium, and broad. The narrow aperture when selected allows a run start only when all three input elements have the same level. The medium aperture when selected permits a run start when the average value of the three element

levels do not differ by more than one third of a quantum step from the level of the first element and neither of the other two elements levels differ by more than one quantum step from the first. The broad aperture when selected allows either or both of the elements subsequent to the first to differ from the first by up to one quantum step of either polarity. For all aperture conditions the first element value, since it is a potential run level, was always made non-conflicting (with CF and run length coding), if necessary, before testing against the run start apertures.

Δ Test: Noise added to the input analog signal tends to severely reduce the usability or confidence of signal variations equal to or smaller than anticipated noise levels. A good signal-to-noise ratio (which is assumed) restricts this signal-noise confusion to small amplitude variations. The evaluational system, when it has established a run length signal value, tests this value against each successive element to determine if the difference is acceptably small. Failure of this test causes immediate termination of the run. The experimental system could be adjusted to accept any one or more of $+1$, -1 , $+2$, -2 quanta levels (1/64 of full scale) of difference.

R Test. The Δ test is usually imposed symmetrically about the run light level; thus, if an assumption is made that ± 2 quanta deviations are permitted, the Δ test would allow a $+2$ quanta deviation followed immediately by a -2 quanta deviation. Such large differences between successive elements is not compatible with the assumption of small noise levels. Because of this intrinsic weakness of the Δ test, the system also imposes an R test which terminates a run if an excessive rate of change exists. The acceptable magnitude of successive differences can be adjusted to 1, 2, 3, or 4 quantum steps.

L Test. As was mentioned in the discussion of the Δ test, noise tends to create a region of amplitude confusion between signal and noise occurrences. Amplitude deviations within this region are probably noise if they are random but are almost certainly caused by signal if they are well ordered, such as successive elements all having the same polarity of deviations from the established run light level. In the experimental system, when several successive elements are found to deviate from the run light level all in the same direction (polarity), the run will be terminated independent of the magnitude of such deviations. In the experimental system, the length of permissible successive element unipolar deviations can be adjusted from one to seven or can be set to infinity by a defeat switch. In addition, an L_2 constraint operating on successive 2-quanta unipolar deviations is included. This L_2 constraint is separately adjustable and has meaning, of course, only if the Δ test constraint permits two quanta deviations. Ideally, failure of an L test should cause termination of the existing run at the beginning of the lengthy deviation. The additional in-process storage and double processing (of the deviant elements) implied by this ideal was judged excessively expensive; consequently, in the experimental system, the run length was terminated for L test failure at the element producing the excessive length.

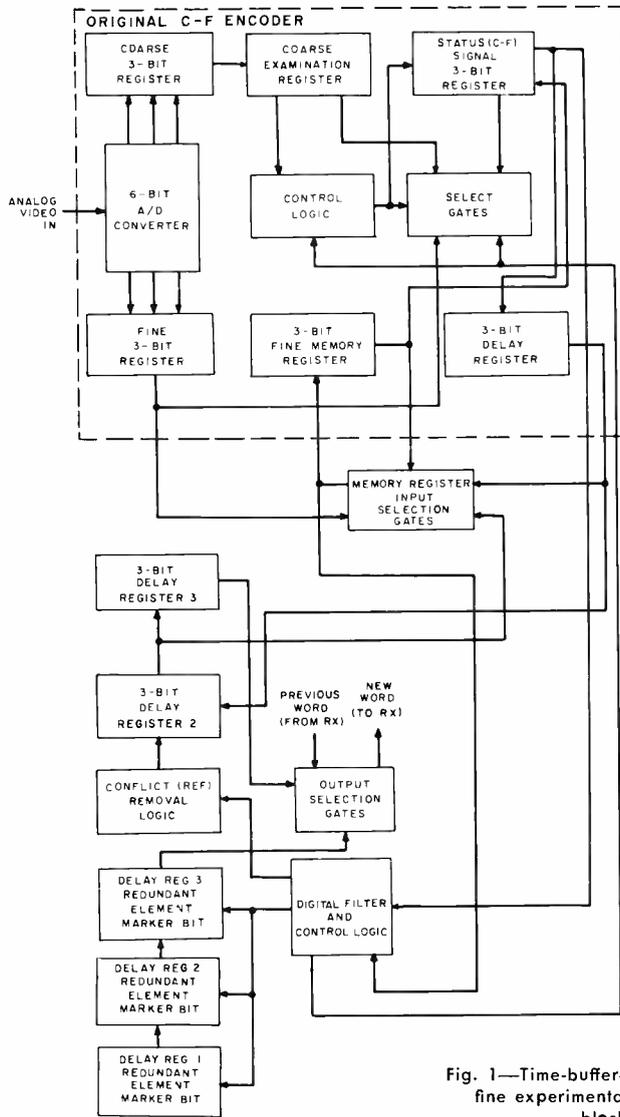


Fig. 1—Time-buffered coarse-fine experimental encoder, block diagram.

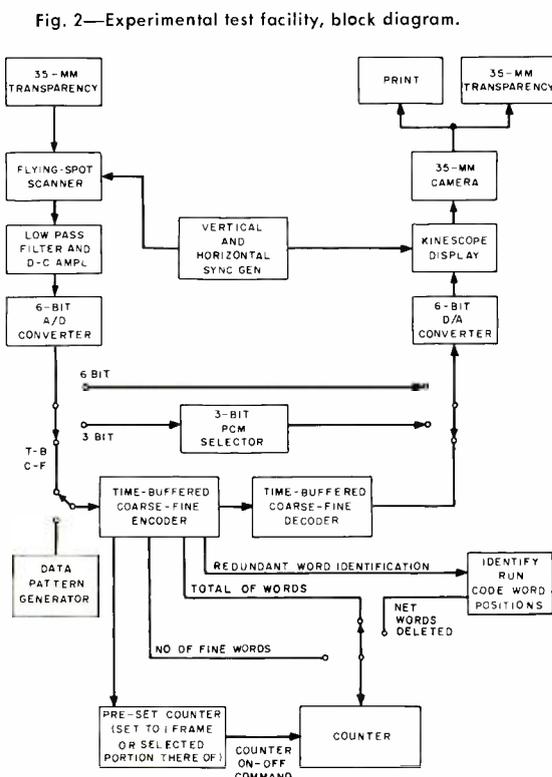


Fig. 2—Experimental test facility, block diagram.



GERALD P. RICHARDS received the BS and MS degrees in electrical engineering from the Massachusetts Institute of Technology in 1953 and 1955 respectively. During 1955 Mr. Richards was employed as MTS at the Bell Telephone Laboratories. Upon return from military service in 1957 he joined the ITT Laboratories in Nutley, N.J. where he performed developmental work on RTL and tunnel diode logic elements. Also at ITT he held overall systems responsibility in the design of a large solid state switching system. In 1961 Mr. Richards joined the Astro-Electronics Division. From 1961 to 1963 he designed special digital data processors. In 1963 Mr. Richards joined the Spacecraft Systems group where he is presently a senior engineer. In this position he has contributed in broad areas of data processing including low carrier frequency FM techniques and high noise FSK and many analysis. Throughout this period he has extensively contributed to design reviews as principal reviewer. A large portion of his time since 1963 has been devoted to the digital TV compression effort. His efforts produced the Improved Gray Scale logic, the concept and logic of the Coarse-Fine system, and the concept and basic logic of the TB CF system. Mr. Richards is a member of Sigma Xi and IEEE.

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System Implementation

The purpose of the processing logic constructed was the evaluation of compression ratios and statistics, and the production of recovered images which are identical to those which would be produced in the complete time-buffering system. To satisfy this purpose, actual redundant element removal and formatting of run-length code words were not required. The logic necessary to accomplish the desired goals need only consist of an augmented CF encoder (Fig. 1), and a normal unmodified CF decoder¹ since all processing could be performed on a one-to-one input-output element real-time basis. The augmentation logic shown in Fig. 1 operates only during the fine-data mode of the CF encoder, performing the two functions of redundant element identification and the removal of all data stream conflicts with run-length code words. This latter function was performable since data-stream conflicts are not influenced by the values of run-length words which would be inserted in a complete system.

Redundant-element identification is performed by a logical realization of the entrance aperture, Δ , R , L , and L_2 constraints as illustrated in Fig. 1. Application of these constraints requires the availability of three elements of data (from the delay registers) and the continued availability of the selected run light level (circulated in the fine memory register). Final identification of redundant elements in the delay register data stream is provided by a marker bit from the control logic. The output selection gates, under the command of this marker bit, provide as the final encoder output either the final delay register (not redundant) or the previously produced element (redundant). Thus, without the removal and reinsertion of redundant elements, a CF-coded equivalent to an actual TB CF data stream has been formed.

EXPERIMENTAL TEST FACILITY

To experimentally evaluate the TB CF compression system, the experimental test facility, (Fig. 2) was constructed. This system can be divided into three groups: input-output equipment, control and data-gathering equipment, and compression-system-checkout equipment.

Input-Output Equipment

The input equipment used to generate the 6-bit digital signal required by the TB CF encoder consists of a flying-spot scanner, a low-pass filter, an amplifier, and a 6-bit analog-to-digital converter.

The flying-spot scanner converts any 35-mm transparency into an analog signal by scanning the transparency using a 5ZP16 kinescope. Manual triggering produces only one frame at a time; each frame period is approximately 34 seconds. The analog signal in each frame consists of 667-by-512 elements sharply filtered to a bandwidth of 5 kHz. The signal is supplied to a 6-bit analog-to-digital converter which produces a 6-bit quantized signal at 10,000 words/second, the Nyquist sampling limit. This 6-bit signal can be sent to the output device for direct display as either a 6-bit or 3-bit PCM picture, or to the TB CF chain for processing. The output device consists of a 6-bit digital-to-analog level converter, a 5ZP16 kinescope display, and 35-mm kinerecording camera.

Control and Data-Gathering Equipment

The TB CF data compressor is designed to allow various processing parameters (Δ , R , L , and L_2) and entrance apertures (narrow, medium, and broad) to be varied independently over a sufficiently large range to allow evaluation of their effects. The equipment employed to gather the required data is capable of examining any horizontal section of the picture up to and including an entire frame. Data taken for those parameters which require the insertion of run-length code words is automatically adjusted during measurements to yield net—not gross—redundancy. The important parameters obtained are the TB CF compression ratio and the number of elements transmitted in the fine mode (of the CF system).

The TB CF compression ratio can be obtained from the formula:

$$\text{Compression Ratio} = \frac{6N_t}{3(N_t - N_d)}$$

where both N_d , the number of words in the section to be deleted from the data stream before transmission, and N_t , the total number of original 6-bit words out of the A/D converter in the section, are measurable quantities.

The number of elements transmitted in the fine mode is an indication of the compressibility and the accuracy of the section. This quantity permits the determination of compression loss resulting from the inclusion of coarse element refinement (CER).

System Checkout Equipment

A digital-data-pattern generator was designed to simulate A/D-converter output

data. Careful analysis of theoretical compressor operation allowed the determination of a 32-word data pattern capable of exercising all TB CF compression functions. Periodic substitution of this data simulator at the encoder digital input provided assurance of correct compressor operation.

EXPERIMENTAL RESULTS AND EVALUATION

Test Conditions

The analog output of the flying-spot scanner was adjusted so that the black-to-white signal swing for each subject encompassed all 64 levels of the A/D converter. This choice of maximum signal range was found to minimize the available compression. To illustrate the increase in the compression ratio that would occur with a reduced black-to-white signal range, as would be the case for most space missions, the nebula photo was processed with 0.6 of full signal range into the A/D converter. Under this condition, the compression ratio increased by 50 percent over that using the full signal range.

Experimental Results

Lunar photographs (Fig. 3) were selected as representative of subjects that might be obtained in an interplanetary mission. Since little *a priori* information exists, the viewer is required to compare the compressed pictures to the original 6-bit representation. The TB CF compressor produced excellent results on this subject as can be seen in Fig. 3a through f.

A picture with a 5.9:1 compression ratio (shown in Fig. 3b) over the 6-bit representation (shown in Fig. 3a) was obtained when using the TB CF system. This compression ratio is equivalent to about one bit per sample, yet the picture details are accurately retained and essentially no degradation can be noticed. For this sample, the system parametric constraints are: medium entrance aperture, $\Delta = \pm 2$, $L = 7$, $L_2 = 3$, and $R = 4$. By relaxing the constraints to broad entrance aperture, $\Delta = \pm 2$, $L = L_2 = \infty$, and $R = 4$, the compression ratio is increased to 6.94:1. This result, shown in Fig. 3d, indicates slight degradation. Long lengths of the same gray level appear in large areas of little detail; notice, however, that the sharp details such as small craters are retained since the system distinguishes these as information. A comparison with the 3-bit PCM representation (Fig. 3c) (always recoverable from the TB CF signal) shows that the compression effects occur only in large

areas of constant coarse level as would be expected. To produce a higher element accuracy representation of the original 6-bit picture, the constraints were tightened to: medium entrance aperture, $\Delta = \pm 1$, $L = 3$, $L_2 = 0$, and $R = 4$. This produces the picture shown in Fig. 3e with a corresponding compression ratio of 4.6:1. Maximum constraints of narrow entrance aperture, $\Delta = 0$, $L = L_2 = 0$, and $R = 0$, produces a nearly pure Coarse-Fine representation while still yielding a compression ratio of 2.86:1 as illustrated in Fig. 3f.

Other important data statistics were obtained for the lunar photograph. One of these data sets provides compression ratio measurements for ten adjacent horizontal sections of the picture. The results shown in Fig. 4a and b for two groups of parametric settings illustrate that the upper sections (low activity) yield about 50 percent more compression than the lower sections (high activity).

Nebula compression results are presented in Fig. 5. The results with the constraints of broad entrance aperture, $\Delta = \pm 2$, $L = \infty$, $L_2 = \infty$, and $R = 4$, shown in Fig. 6b, compares favorably with the 6-bit PCM results shown in Fig. 5a. Essentially all of the stars were

reproduced using the TB CF system, which provided a compression ratio of 6.28:1.

The 6-bit representation of the nebula shown in Fig. 5c, has a video signal range of 60 percent of the A/D converter range; i.e., about 40 of the 64 possible intensity levels. Fig. 5d, produced by the application of compression to this reduced input signal, shows a compression ratio of 9.54:1 with constraint settings identical to those used to obtain Fig. 5b.

Data Refinement

Because of the basic nature of the Coarse-Fine system, the TB CF data can also be augmented to include the fine information of its coarse element content. Although no photographs of such augmented TB CF could be made because of equipment limitations, the coarse content of some photographs was measured to allow calculation of available augmented TB CF compression. A comparison of compression available if fine augmentation were to be added to the photographs is presented in Table I. The growth in compression loss at high initial TB CF ratios is of little consequence since data accuracy requirements necessitating augmentation would not permit the relaxed run restrictions required to produce such high compressions.

TABLE I.—Compression of Lunar Photo Available with Augmented TB CF with 88.5 Percent of the Elements in Fine Mode and 11.5 Percent of the Elements in Coarse Mode.

Initial TB CF Compression Ratio	Net Augmented TB CF Compression Ratio
2.86:1	2.45:1
4.6:1	3.64:1
5.9:1	4.40:1
6.94:1	4.96:1

CONCLUSIONS

The photographic and numerical evidence obtained demonstrates that application of the Time-Buffered Coarse-Fine concept can in fact produce excellent results both in reproduced picture quality and in the degree of compression available. Compression ratios from 4.5:1 to 6.3:1 have been obtained with excellent quality. Even higher compression ratios are possible if a somewhat lower quality reproduction will suffice. The most effective control was found to be the L constraint which could minimize or eliminate the streaking effect evident in many forms of statistical compression.

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Fig. 3—Lunar photographs.

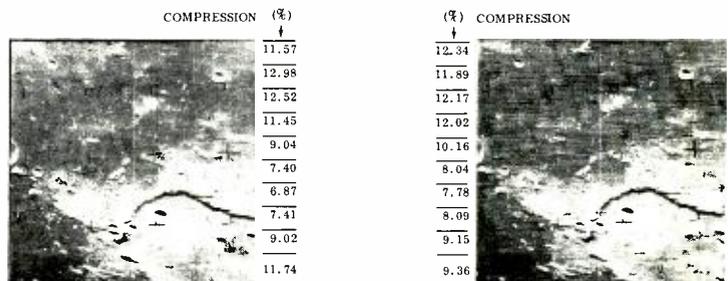
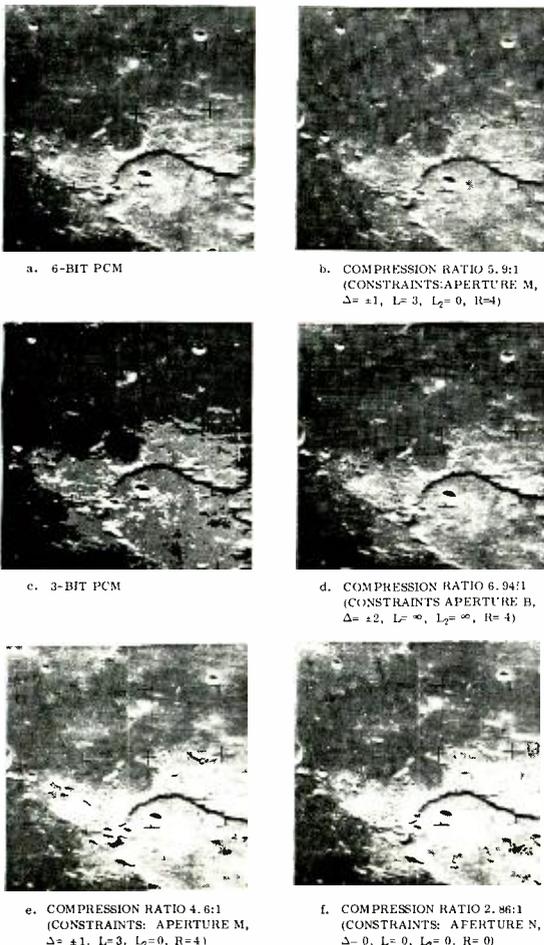


Fig. 4—Distribution of compression in Lunar photographs for two groups of constraint settings.

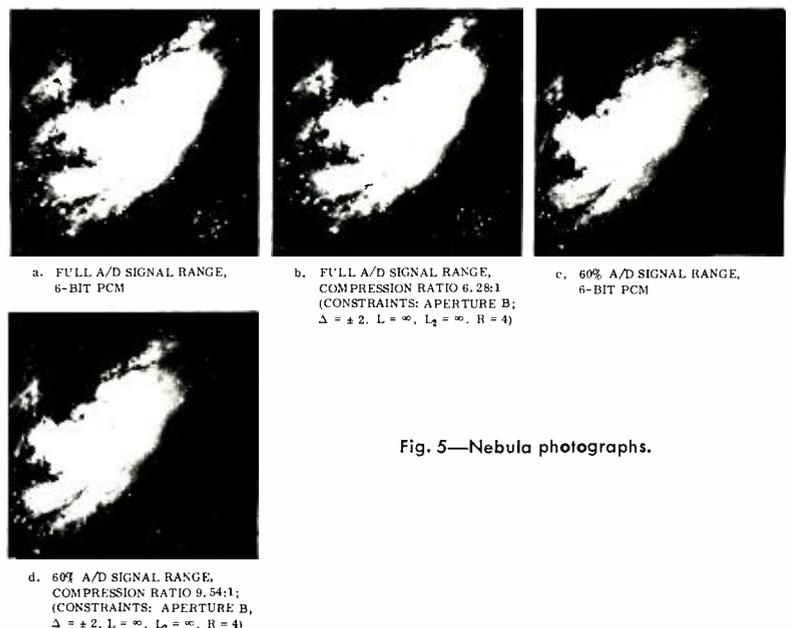
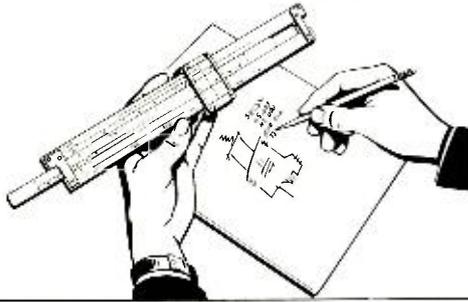


Fig. 5—Nebula photographs.

Engineering and Research NOTES

BRIEF TECHNICAL PAPERS OF CURRENT INTEREST



Dollars versus Protection in Destructive Testing



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Destructive test sampling differs from any other sampling in two very important ways: it is more expensive and the disposition of rejected lots is different. Ordinarily, a rejected lot can be screened or tested 100%. With destructive testing this is impossible; hence the average outgoing quality limit (AOQL) concept of sampling (predicated upon the 100% sorting of rejected lots) is lost.

How large a sample should we take for a destructive test? A frequent solution is to pick out some small number like 3 pieces, and to allow zero defectives. Another answer is to pick up one of the S-level plans of MIL-STD-105D (for expensive testing) and then select some safe-sounding acceptable quality level (AQL). Such an action has a certain psychological defense: one is supposed to take a sample before accepting anything—and now one has done this. But in selecting a sampling plan intelligently, two important questions arise: 1) What protection of quality should the plan give? Specifically, what consumer's and/or producer's risk are we willing to take and for what quality level? 2) What is the total cost of the testing? The relation of protection to cost is the important consideration in choosing a plan.

How this can be done is best illustrated by taking a specific case and constructing a cost model. As an example we can choose a plan for acceptance sampling of a pyrotechnic device. These devices cost \$100 each in lots of 1000; testing costs \$10 each. In this case, it has been decided that the protection afforded by MIL-STD-105D, level II, 4% AQL is adequate. Since the AQL is concerned with producer's rather than consumer's risk, we consult MIL-STD-105 and find that this plan would provide a 10% probability of accepting lots which are 14.2% defective (in Dodge-Romig nomenclature, lot tolerance percent defective (LTPD) of 14.2% for beta of 0.10). One other factor enters into consideration: What quality of lots will be presented to our inspection plan for acceptance? Since we have no way of knowing this, and since it will affect costs, it will be necessary to compute costs over a wide range of incoming lot quality (Process Average).

The basis for comparing the various sampling plans is the *total cost/good unit accepted*. Some of the elements involved are the lot cost of 1) purchasing (including handling, etc.) 2) testing, and 3) rejection. It is assumed that rejected lots cannot be used and are not returnable to the vendor; their cost is chargeable against the sampling plan. Since we are comparing various plans on the basis of providing the same consumer protection, this serves to penalize a plan which would reject an inordinately large number of lots in order to provide that protection.

The net cost of testing/usable unit accepted is:

$$C_{TV} = \frac{NC_v + nC_T}{P_A(N - n)} - C_u$$

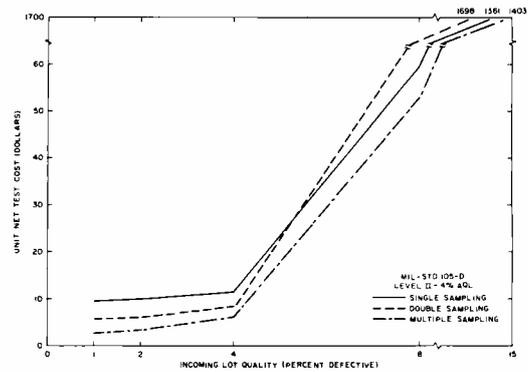


Fig. 1—Test cost versus incoming quality for single, double, and multiple sampling.

where N is lot size (1000 for the present case); n is size of sample tested (or average sample number); C_v is unit cost of acquiring item (purchase price + overhead and handling—\$100 in our example); C_T is unit cost of test operation (including overhead—\$10 for this example); C_{TV} is net unit cost of testing, per usable unit acceptable; and P_A is probability of acceptance of the lot under the plan in question.

The denominator is the expected number of usable pieces that will be realized from each lot. The numerator is the total cost of acquiring and testing a lot.

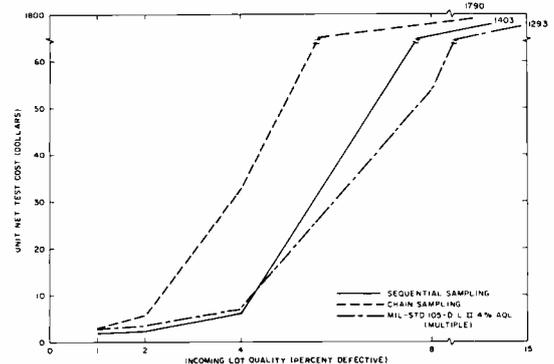
Assume an incoming lot quality of 4% defective, using MIL-STD-105D, level II, single sampling. From that table, $n = 80$. Probability of acceptance is computed to be 0.982.

Thus,

$$C_{TV} = \frac{(1000 \times \$100) + (80 \times \$10)}{0.982(1000 - 80)} - \$100 = \$11.58$$

Applying the same formula to lots of incoming lot quality ranging from 1% to 15% defective results in the graph shown in Fig. 1. Cost goes up sharply as the incoming lot quality exceeds 8% defective, due to the large number of lots being rejected and included in the total cost. Repeating the computation with the corresponding MIL-STD-105 double and multiple sampling plans yields the data graphed in Fig. 1. Now, however, the average sample number (instead of sample size) is used for n . The double and multiple plans are substantially lower in cost for good incoming lot quality, because the single plan has a large fixed sample size. Double and, to an even greater extent, multiple plans will accept a very good lot with a much smaller sample. A sequential plan has been developed to match as closely as possible the MIL-STD-105D plans in consumer protection since a sequential plan will provide a given level of protection with an even smaller sample. Table I shows the formulas and cost computations. A matching chain sampling plan was also developed. These are graphed in Fig. 2.

Fig. 2—Test cost versus incoming quality for sequential and chain sampling.



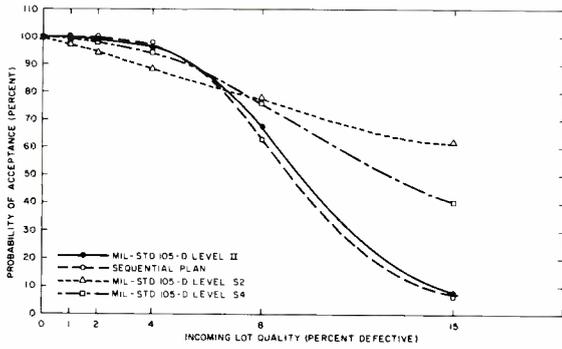


Fig. 3—Operating characteristic curves.

The question is often asked: For destructive testing, why not use the MIL-STD-105 S-level plans? Since these use much smaller samples, it was decided to compare them with the plans above, even though their consumer protection was drastically poorer than that demanded. The results were that the costs are about the same as a sequential plan for 1% lot quality, higher for 2% and 4% lots. Only when lot quality becomes worse than 4% are they cheaper, and then only because they accept a very high percentage of inferior lots. Their spectacularly poor consumer protection is shown in Fig. 3, comparing operating characteristic curves of the plans above.

Summarizing, the requirement of lowest cost demands rejecting the fewer possible number of lots while holding a stated level of consumer protection. This calls for a plan with a high discrimination (low operating ratio) and also for holding down sampling size. These two requirements seem to be incompatible: a high degree of discrimination is usually associated with large sample sizes. However, as we have shown, use of multiple or sequential plans will, for a given level of protection, require the smallest possible sample size.

If the situation allows the use of variable instead of attribute sampling, greater economy may be effected. Each sample piece tested for a variable response yields more information than a piece tested for an attribute. Hence the necessary information can be gleaned from a smaller sample.

An alternative to destructive sampling may be the use of a non-destructive test which correlates highly with the destructive test. If this can be found, it is especially valuable as a means of sorting (screening) rejected lots for good pieces.

Choice of a sampling plan for a destructive test need not be a matter of choosing some arbitrary number, or of picking a plan blindly from a table. A systematic approach calls for the following steps: 1) Define the parameters and conditions of the problem; 2) Establish the costs of each element; 3) Formulate a mathematical expression for the cost; 4) Using that expression, plot the costs versus incoming lot quality for various types of plans; and 5) Choose the best plan for the case at hand.

Two valuable alternatives are also worth consideration: 1) Find a correlating nondestructive test; or 2) Use variables sampling instead of attributes.

Armed with this approach, the cost-to-protection ratio can be optimized for any set of conditions.

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TABLE I—Sequential Plan to Match MIL-STD-105D, Level II, 4% AQL Single Sampling Plan (N = 1000)

	Incoming Lot Quality				
	1%	2%	4%	8%	15%
Prob. Acc. (%)	99.9	99.9	98.2	63.0	7.5
Average Sample	21.0	21.0	38.0	63.0	36.0
Net Unit Test Cost (\$)	2.35	2.36	6.22	70.56	1293.88

where ASN = average sample number. α = Producer's Risk, β = Consumer's Risk, P'_1 = lot quality corresponding to α , and P'_2 = lot quality corresponding to β ; $\alpha = 1.8\%$; $\beta = 7.5\%$; $P'_1 = 0.04$; and $P'_2 = 0.15$

$$h_1 = \frac{\log \frac{1-\alpha}{\beta}}{\log \frac{P'_2(1-P'_1)}{P'_1(1-P'_2)}} = 1.78 \quad h_2 = \frac{\log \frac{1-\beta}{\alpha}}{\log \frac{P'_2(1-P'_1)}{P'_1(1-P'_2)}} = 2.73$$

$$S = \frac{\log \frac{(1-P'_1)}{(1-P'_2)}}{\log \frac{P'_2(1-P'_1)}{P'_1(1-P'_2)}} = 0.0841 \quad X = -1.78 + 0.0841n \text{ (Accept Line)}$$

$$\quad \quad \quad X = 2.71 + 0.0841n \text{ (Reject Line)}$$

$$ASN = \frac{P_A \log \frac{\beta}{(1-\alpha)} + (1-P_A) \log \frac{(1-\beta)}{\alpha}}{P' \log \frac{P'_2}{P'_1} + (1-P') \log \frac{(1-P'_2)}{(1-P'_1)}}$$



Mechanized Reflow Soldering of Flatpack Integrated Circuits

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Reflow soldering is the fusing together in assembly of the solder which has been pre-coated on the parts to be joined. This fusing together is in the nature of a "sweated" solder joint.

For electrical attachment from only one side (surface attachment) the integrated circuit rests on the circuit board so that the leads form lap joints with the circuit board pads.

The mechanized reflow soldering method employs a heated wedge-shaped soldering tip that contacts all of the leads of an integrated circuit at one time. Inasmuch as the heat is applied externally (as with a hand soldering iron) no electrical damage can occur to the semiconductor, providing known precautions are taken with respect to leakage and grounding. The temperature of the soldering tip is controlled by a fool-proof means so that no damage can occur from overheating. Mechanized means are used to apply the soldering tip, control the time, and hold the soldered joint until it solidifies.

A thermo-magnetic temperature controlled hand soldering iron, that utilizes the Curie Temperature of an alloy slug in the soldering tip to make and break the electrical circuit, had already been marketed.* (The Curie Temperature is the temperature of magnetic transformation below which a metal or alloy is magnetic and above which it is paramagnetic.)

A wedge-shaped tip of this type, having the prescribed size and shape for the particular job at hand, was designed and fabricated. In fact, several tips were built to permit experimentation with the variables of time and temperature. Due to the intimate thermal path provided by the heat source, the author found the most efficient operation with a 700°F tip, impressed on the leads for 2 seconds. Figs. 1 and 2 show a working feasibility model. A description of this model follows:

The device uses a specially designed wedge soldering tip that spans all the leads over nominally a 0.250 inch span with a width of flat section of about 0.030 inch, large enough to set down on the flat of the lead. The tip is heated to a specified temperature, controlled by a Curie Temperature sensing device in the tip. The tip is impressed on the leads for a specified period of time, then raised. Before application of heat, a specially-designed spring member forces the leads flush against the circuit on either side of the soldering tip. As little as 0.050 inch total space may be available for the tip and springs together. The tip comes down, reflows the solder, and is released while the springs remain in place until the joint solidifies. Then the springs are raised. The springs serve the two-fold purpose

of holding the joint in place until the solder solidifies, and acting as a heat dissipator to prevent overheating of the integrated circuit. The springs are lined with a thermally-insulating plastic film (H-Film or Teflon). This film also acts to provide lubricity with the soldering tip. This device can be timed so that all actions are mechanized, and the part to be soldered can be moved from position to position. Also, a multiple device can be arranged to reflow solder all of the leads on both sides of the integrated circuits at one time. Further, a multiple device can be arranged to reflow arrays of leads of several integrated circuits at one time.

An auxiliary technique employs a plastic to tie down the body of the integrated circuit so that all the integrated circuits can be pre-placed with the leads in position at an assembly station before the reflow operation begins. Dow 271 or equivalent can be used. This material was found to be ever-plastic so that final dimensional adjustment, if required, can be made at the work station. A soldering tip of greater width can be provided for integrated circuits with more than five leads on a side.

Recommended preparation of the parts to be joined is to have at least one surface flat, so that the parts do not slide with respect to each other during the plastic flow of the solder. Although the leads of the integrated circuit may be dip soldered, the solder coating on the circuit board should be quite thin to avoid the displacement of the integrated circuit lead with respect to the circuit pad during the reflowing.

In the demonstration, the integrated circuit leads were pre-solder dipped, and the etched circuit board was solder electroplated. The body of the integrated circuit was preplaced on the circuit board with a plastic adhesive that permitted final adjustment of the leads with respect to the circuit board pads. A single drop of Dow 271 applied with the edge of a toothpick or similar applicator was placed on each part to be joined. The parts were allowed to set for fifteen minutes before placing them together. Final adjustment was made at any time thereafter, positioning the leads with respect to the circuit pads. The assembly was fluxed with an activated rosin flux, conforming to MIL-F-14256, Type A. The author was successful with the use of this flux brushed over the assembly and permitted to air dry or about fifteen minutes before reflowing.

Upon applying the tool to the joint, the first apparent indication of reflowing will be the activation of the flux. Subsequent to the flowing of the flux, the solder will reflow. The solder reflow will be visually observable under the magnifier. An acceptable soldered connection as made, is shown in a representative macrophotograph (Fig. 3). Smooth solder fillets (criteria for suitable soldering) are observed. A representative metallographic cross-section is shown in Fig. 4, at 100 magnifications. A smooth solder transition is shown. This admittedly simple working model proved the feasibility of rapid reflow soldering by an externally-applied heat source.

From this concept, a production machine designed for high speed reflow soldering of adequately pre-tinned surfaces has been marketed. The machine is an efficient and economical production method of interconnecting flat pack integrated circuits and printed circuit boards. Efficiency and economy are achieved by the unique method of soldering a complete flat pack (all leads on both sides) in one single operation. Two soldering tips of sufficient width to accommodate the various multi-lead flat packs are indirectly heated using the thermo-magnetic temperature control system. The flat packs are placed in a holder which aligns the component with the circuit pads, and acts as a heat sink. Alternatively, equipment modification permits pre-placement of the flat packs, and the holder serves the single purpose of a heat sink. A foot switch then activates an automatic soldering cycle, during which the tips are lowered to the work, dwell, and return to their retracted position. Wettable soldering tips are used to provide the most efficient thermal path between the tips and the work area. The heating elements are low voltage (24 volts), which insure long life. All parts of the machine, which contact the work or operator, are grounded. The total time needed to position the flat pack and to complete the soldering operation is a few seconds, dependent on the dwell time of the soldering tips, which is adjustable from less than 1 second to 6 seconds.

RCA Missile and Surface Radar Division recently has completed an order for a series of integrated circuit modules for a large ground support space system for the Burlington Plant. The soldering of the flat packs to the board circuitry was performed with the soldering machine. As reported by the Manager of Manufacturing Engineering, Mr. J. P. Stratton: "The operation was most successful, producing good quality solder joints at acceptable cost." The time to attach a flat pack is in the order of a minute compared to an average 15 minutes for hand methods. Furthermore, additional time (cost) savings can result from more experience in use of the machine and from the decreased amount of repairs required.

Reference: R. G. Clarke and J. W. Kaufman, "Packaging High-Density Circuits," *Assembly Engineering*, June 1966.

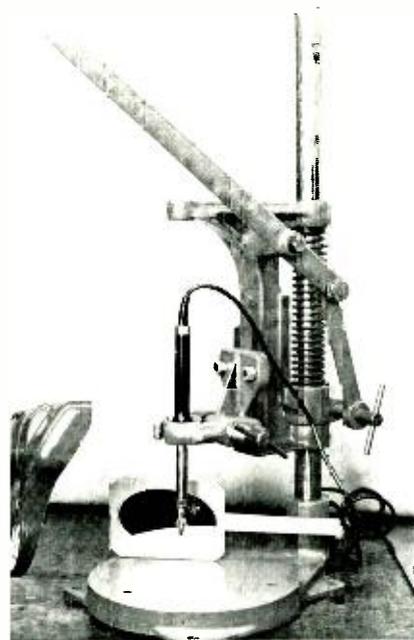


Fig. 1—Reflow soldering tool.

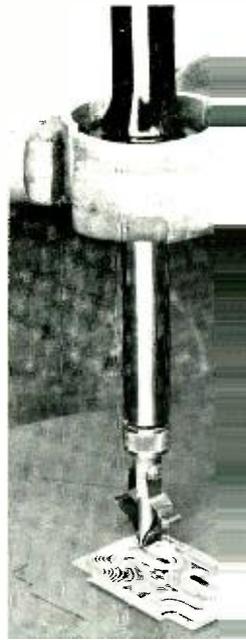


Fig. 2—Close-up of reflow soldering tool.

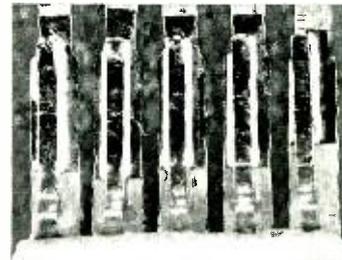


Fig. 3—Macrophotograph showing all leads on one side of a flat pack soldered with the feasibility model.

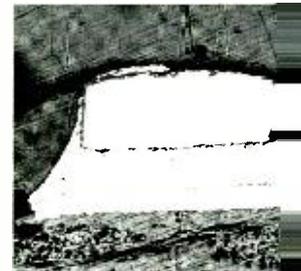


Fig. 4—Photomicrograph of cross-section of an individual solder lead, showing smooth solder fillet and excellent bond.

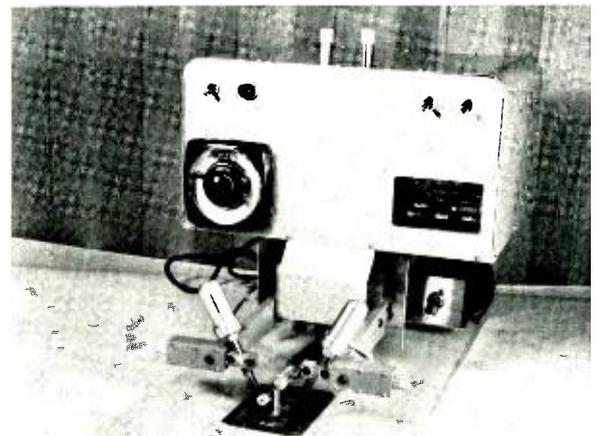
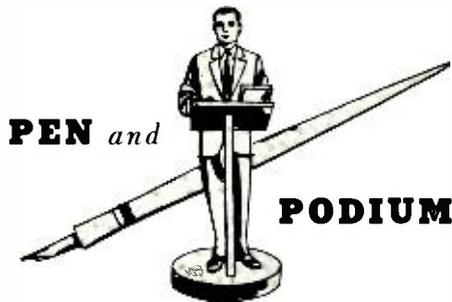


Fig. 5—Weller integrated circuit soldering machine. (The author has the permission of the Weller Electric Company for using the description of their equipment.)



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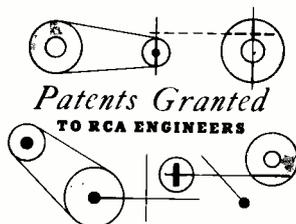
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Logic Circuitry Adapted to Control the Transfer of Information to a Storage Element—E. Gloates, L. L. Rakoczi (BCD, Cam) U.S. Pat. 3,325,790, June 13, 1967

Skew Correction System—R. H. Jenkins (BCD, Cam) U.S. Pat. 3,325,794, June 13, 1967

Indexing Device—B. F. Floden (BCD, Cam) U.S. Pat. 3,326,626, June 20, 1967

WEST COAST DIVISION

Card Transport System—J. W. Rabek (WCD, Van Nuys) U.S. Pat. 3,329,424, July 4, 1967

RCA LABORATORIES

Integrated Semiconductor Logic Circuits—J. R. Burns, R. A. Powlls (Labs, Pr) U.S. Pat. 3,328,604, June 27, 1967

Nonreciprocal Solid State Waveguide and Devices Utilizing Same—M. Toda (Labs, Tokyo) U.S. Pat. 3,327,247, June 20, 1967

Dynamic Raster Distortion Correction Circuit Having Four Window Magnetic Circuit—W. H. Barkow, R. M. Christensen (Labs, Pr) U.S. Pat. 3,329,861, July 4, 1967

Ordered Retrieval of Information Stored in a Tag-Addressed Memory—M. H. Lewin (Labs, Pr) U.S. Pat. 3,329,937, July 4, 1967

Semiconductor Device Fabrication—J. H. McCusker (Labs, Pr) U.S. Pat. 3,331,125, July 18, 1967

Decoder Circuits—H. Kihn, W. E. Barnette (Labs, Pr) U.S. Pat. 3,329,827, July 4, 1967

ADVANCED TECHNOLOGY DIVISION

Machine for Composing Ideographs—F. E. Shashoua, W. R. Isom (AppRes, Cam) U.S. Pat. 3,325,786, June 13, 1967

Air Bearing Data Storage Apparatus—C. Lauxen (AppRes, Cam) U.S. Pat. 3,329,941, July 4, 1967

Air Bearing Data Storage Apparatus—M. L. Levene, C. Lauxen (AppRes, Cam) U.S. Pat. 3,329,942, July 4, 1967

COMMUNICATIONS SYSTEMS DIVISION

Minimum Error Detecting Circuit—F. L. Putzrath (CSD, Cam) U.S. Pat. 3,199,014, August 3, 1965 (assigned to U.S. Gov't)

Parallel Active Circuit Elements with Provision for Power Distribution—L. A. Harwood (CSD, Cam) U.S. Pat. 3,327,238, June 20, 1967

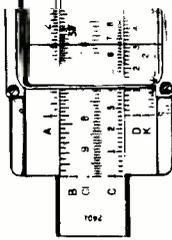
Remote Monitoring System—H. E. Goldstine, E. Cohen (CSD, New York) U.S. Pat. 3,327,289, June 20, 1967

DEFENSE ELECTRONICS PRODUCTS

Electronic Switching—L. Sickles, II (DEP, Cam) U.S. Pat. 3,327,133, June 20, 1967

RCA COMMUNICATIONS DIVISION

Regenerator—R. Konian (RCA Comm, New York) U.S. Pat. 3,327,230, June 20, 1967



NEW MAGNETIC-TAPE TYPESETTER

RCA's Graphic Systems Division recently demonstrated the first magnetic-tape-driven electronic typesetter, the Videocomp 70/822, at the Mechanical Conference of the American Newspaper Publishers Association in Kansas City, Missouri.

Compared to paper tape, the new magnetic tape increases computer typesetting speed by a factor of 300, reduces tape storage requirements by 98%, and provides greater operating flexibility and accuracy. By using the 30,000-character-per-second magnetic tape units, the computer can produce enough tape in one minute to keep the Videocomp 70/822 setting type for almost an hour—more than enough time to set a full section of a metropolitan daily newspaper.

In most computerized typesetting operations, copy is fed into the computer on paper tape. The computer justifies and hyphenates the copy, producing an output paper tape at the rate of 100 to 300 characters per second. This range of speeds is ideal for mechanical typesetters. However, in electronic composition, it is a serious drawback since the RCA Videocomp, which sets type on a high resolution cathode-ray tube, can read characters at 650 characters a second.

As a result, up to six minutes of computer output could be required to produce one minute of input to the Videocomp typesetter.

COMPUTER TO BE USED AT NEWARK COLLEGE OF ENGINEERING

A new RCA Spectra 70/35 computer system has been ordered by Newark, N.J., College of Engineering to handle a variety of assignments in the classroom, in the laboratory and in the office.

According to Dr. William Hazell, NCE Dean and Vice President, the system will offer "a vastly larger range of engineering training and research opportunities for students and faculty than our present system. The new system will enable our students to solve elaborate problems as part of their career preparations, and will give the faculty more freedom to conduct far more complex research than previously has been possible."

MINIATURE TV CAMERA FOR SPACE

A tiny television camera (6 $\frac{7}{8}$ x 3 x 1 $\frac{1}{2}$ inches) weighing about two pounds has been developed by the Astro-Electronics Division for potential use in space exploration. This device is the smallest TV camera ever produced at AED, the producer of more than 150 space TV cameras, including those for the TIROS and NIMBUS weather satellites and the series of RANGER spacecraft that gave the world its first close-up views of the Moon.

According to Max Mesner, RCA Manager of TV Camera Systems, "Installed in a manned spacecraft, it [the camera] could observe astronaut actions and reactions during a flight. The camera could be detached and hand-held by an astronaut to provide panoramic views of the space environment, or used outside the spacecraft following a Moon or planetary landing." Working in conjunction with a signal converter, the camera could also relay live pictures from space to home television audiences.

Mr. Mesner also said that the camera could function equally well unattended. On unmanned programs, for example, it could "watch" experiments and spacecraft elements requiring visual observation by scientists on the ground.

Resolution of the camera is 600 lines, slightly better than commercial television standards, and it has a 1 $\frac{1}{2}$ second frame rate—For further information contact: Thomas L. Elliott, RCA Defense Electronic Products, Moorestown, N.J., area code 609, 963-8000, ext. PM 2268.

COMPUTER PROGRAMS FOR CIRCUIT ANALYSIS

Engineering activities in Camden, Moorestown, Hightstown, and Lancaster have been making increased use of computer programs for circuit analysis work. Electronic Circuit Analysis Program (ECAP) is one of the most widely used, and is capable of DC, AC, or transient circuit analysis. The ECAP package includes a 188-page user's manual, and a program tape. The source deck in FORTRAN II, consists of approximately 8,000 cards and was originally compiled by Norden, Autonetics, and IBM.

Have you returned the readership survey delivered with this issue of the RCA ENGINEER?

A Workshop Course, consisting of four 2-hour sessions, is available to provide engineers with a working knowledge of ECAP, although program specialists are available in Central Engineering.

Analysis of high-speed switching circuits can be performed using the relatively new "Automated Digital Computer Program for Determining Response of Electronic Circuits to Transient Nuclear Radiation" (SCEPTRE). The 15,000-card SCEPTRE source deck in FORTRAN IV provides increased program capabilities, including the handling of several types of non-linearities.—Further information on ECAP or SCEPTRE workshops or related analytical services can be obtained from D. R. Crosby, Building 1-6-5, Ext. PC 4864.

SERVICE COMPANY RECEIVES MULTI-MILLION-DOLLAR CONTRACT

RCA Service Company has been selected by NASA to operate and maintain portions of the Space Tracking and Data Acquisition Network (STADAN). The estimated total value of the STADAN contract is approximately \$60 million, with the initial three-year agreement accounting for \$38 million. In addition, there are options for two one-year extensions, as well as incentive provisions based on performance.

Under the NASA contract, the major areas of the RCA responsibility are the tracking stations at Rosman, North Carolina, and Fairbanks, Alaska. In addition, the Service Company will operate some of the various satellite Control Centers at Goddard Space Flight Center, Greenbelt, Maryland.

The global mission of STADAN is to acquire data from unmanned satellites and

space vehicles launched by the United States Government and cooperating foreign government groups. This includes scheduling, monitoring, and evaluating operations of such space vehicles as TIROS, NIMBUS, Orbiting Solar Observatory (OSO), Orbiting Geophysical Observatory (OGO), Applications Technology Satellite (ATS), and the Geodetic Satellite (GEOS), among others.

ENGINEER RECEIVES \$1,000 FOR THERMOCOUPLE INVENTION

An idea for a small, fast-responding, non-destructive, and highly accurate temperature measuring device (thermocouple) used in the testing of spacecraft has earned a \$1,000 award from the National Aeronautics and Space Administration for an engineer formerly at the RCA Space Center near Princeton, New Jersey, and presently employed at the RCA Electronic Component and Devices Division at Lancaster, Pa. Richard C. Turner, a mechanical engineer, is the recipient of the award made by the NASA Inventions and Contributions Board. He is the third Astro-Electronics Division member to be so honored in the year 1967.



R. C. Turner

Mr. Turner devised an improved thermocouple for civilian and military applications that is compact (11/16 by 5/16 inches) and accurate. Combining a fine thermocouple wire, an adhesive tape backing with a metallized reflector, and an insulating block, this thermocouple has widespread application in the environmental testing of spacecraft and spacecraft components as well as in the commercial field for the measurement of temperatures. Because of the ease of application and removal, large savings are realized both in time and in the prevention of damage to the equipment undergoing test.

The small thermal mass of the thermocouple results in a reduced time delay in temperature measurements and enables a highly accurate temperature reading; a reflective backing reduces inaccuracies from radiated heat from nearby sources.

The new invention was first used in the environmental testing of subsystems and components of the RANGER program in 1963. Since then it has been used in the testing of almost all of the spacecraft subsystems provided by RCA as contractor or major subcontractor, including the NIMBUS, TIROS-ESSA, and LUNAR ORBITER programs. NASA has filed a patent application for the new invention.—S. Weisberger

STAFF ANNOUNCEMENTS

R. A. Krinsley has been elected Vice President, Random House, Inc., by the Board of Directors of Random House, Inc.

M. E. Karns has been appointed Vice President, Patents and Licensing; he will report to **Dr. G. H. Brown**, Executive Vice President, Research and Engineering. **M. E. Karns**, Vice President Patents and Licensing, announced the organization of Patents and Licensing as follows: **S. S. Barone**, Staff Vice President, International Licensing; **J. J. Benavie**, Staff Vice President, Domestic Licensing; and **J. V. Regon**, Director, Patent Operations.

A. F. Inglls, Division Vice President, Engineering and Merchandising Department, Broadcast and Communications Products Division, announced the organization of the Engineering and Merchandising Department as follows: **J. H. Cassidy**, Manager, Sales Support and Services; **B. E. Fincher**, Manager, Radio Station Equipment Merchandising; **T. M. Gluyas**, Manager, Broadcast Audio and Transmitter Engineering; **H. N. Kozanowski**, Manager, TV Advanced Development; **A. H. Lind**, Manager, Studio Equipment Engineering; **R. L. Rocamora**, Manager, Antenna Engineering and Merchandising; **W. B. Varnum**, Manager, Studio Equipment Merchandising; **R. M. Williams**, Manager, TV Transmitter Merchandising; **H. S. Wilson**, Manager, Microwave Engineering and Instructional TV Merchandising and Engineering; and **J. E. Young**, Manager, Systems Engineering and Administration.

J. Hillier, President, Laboratories RCA, Inc. appointed **Dr. Philip K. Baltzer**, Director of Research, Laboratories RCA, Inc. (Tokyo).

S. W. Cochran, Division Vice President and General Manager, Graphic Systems Division, announced the organization of the Graphic Systems Division as follows: **A. H. Coleman**, Manager, Product and Programming Planning; **P. J. Cuomo**, Manager, Personnel; **G. E. Dashiell**, Division Vice President, Marketing Department; **K. Hesdoerffer**, Manager, Manufacturing Operations and Product Assurance; **R. V. Luongo**, Controller, Finance; and **G. O. Walter**, Chief Engineer, Engineering Department. **G. O. Walter**, Chief Engineer, announced the Engineering organization as follows: **H. N. Crooks**, Manager, Product Development; **J. C. Furlong**, Manager, Drafting; **D. Meredith**, Manager, Programming Development; **A. I. Pressman**, Staff Engineering Scientist; and **D. S. Sikora**, Leader, Systems and Project Management.

The Board of Directors of Random House School and Library Service, Inc., has elected **S. P. Berner** Vice President, Random House School and Library Service, Inc. Mr. Berner will report to **R. L. Bernstein**, President, Random House, Inc.

A. K. Weber, Vice President, Defense Electronic Products, has appointed **W. J. Sneck** Manager, Manufacturing Engineering and Facilities Services and **M. M. Tall** Manager, Defense Product Assurance.

F. L. McClure, Staff Vice President, Organization Development, appointed **H. E. Roush** Director, College Relations.

R. L. Werner, Executive Vice President and General Counsel, appointed **R. B. Houston** Staff Vice President and General Attorney, Defense-Industrial Products and Staff Activities. In this capacity, Mr. Houston will be responsible for furnishing legal services for Defense Electronic Products, Electronic Data Processing, Broadcast and Communications Products Division,

RCA Laboratories, Graphic Systems Division, New Business Programs, and Staff Activities for the manufacturing and service divisions. Mr. Werner appointed **W. A. Osterling** Staff Vice President and General Attorney, Consumer Products, Components, and Services. In this capacity, Mr. Osterling will be responsible for legal services for RCA Sales Corporation, RCA Victor Home Instruments Division, RCA Victor Distributing Corp., RCA Victor Record Division, RCA Magnetic Products Division, RCA Electronic Components and Devices, RCA Service Company, and RCA Parts and Accessories.

R. B. Houston, Staff Vice President and General Attorney, Defense-Industrial Products and Staff Activities, announced the following assignments of responsibility: **G. E. Hollingsworth**, Senior Staff Counsel, Defense-Industrial Products; **J. W. Bohlen**, Senior Counsel, Electronic Data Processing; **G. E. Hollingsworth**, Acting Senior Counsel, Broadcast and Communications Products Division, RCA Defense Electronic Corporation; **W. A. Wyatt**, Counsel, Communications Products Marketing Department, DEP Advanced Technology and Equipment Maintenance and Support; **R. V. Faragher**, Senior Counsel, All U.S. Government Contract matters, Communications Systems Division; **C. T. Attix, Jr.**, Senior Counsel, RCA Laboratories, Astro-Electronics Division, Graphic Systems Division, New Business Programs; **L. J. Gardner**, Counsel; **W. J. Neff, Jr.**, Counsel, Missile and Surface Radar Division; **P. J. Salve**, Counsel, West Coast Division, including Aviation Equipment Department and west coast activities of RCA Instructional Systems; **D. A. Thorn**, Counsel, Aerospace Systems Division; **A. D. Kennedy, Jr.**, Senior Staff Counsel, Staff Activities including Manufacturing Services and Materials, and Real Estate; **R. V. Runyan**, Senior Counsel, Personnel; **J. J. Farrell**, Counsel; and **F. E. Pingon**, Counsel.

W. A. Osterling, Staff Vice President and General Attorney, Consumer Products, Components and Services, announced the following assignments of responsibility: **J. Alderman**, Senior Staff Counsel, Consumer Products, Components and Services; **J. Alderman**, Acting Senior Counsel, RCA Victor Home Instruments Division, RCA Sales Corporation; **J. A. Kutch**, Counsel; **D. B. Beresford**, Counsel; **W. H. Dyczko**, Senior Counsel, RCA Victor Record Division; **L. Wernick**, Counsel; **R. Udell**, Counsel; **E. B. Packard, Jr.**, Counsel; **E. P. Hirsch**, Senior Counsel, RCA Electronic Components and Devices; **R. H. Tallant**, Counsel; **R. J. Modersbach**, Counsel; **H. C. Tily**, Senior Counsel, RCA Service Company; **J. P. Lynch**, Counsel; **R. H. Beber**, Counsel; and **W. A. Wyatt**, Counsel, RCA Victor Distributing Corp., RCA Parts and Accessories.

R. H. Pollack, Manager, Solid State Power Device Engineering, announced the organization of Solid State Power Device Engineering, Solid State and Receiving Tube Division as follows: **M. B. Alexander**, Administrator, Engineering Administration; **W. E. Babcock**, Staff Engineer; **D. R. Carley**, Manager, RF Power Transistor Design; **F. Gusler**, Resident Engineer—Findlay; **M. F. Lamorte**, Manager, Optical Devices and Tunnel Diode Engineering; **H. Miller**, Manager, Power Device Prototype Fabrication; **A. M. Splinter**, Manager, Photocell Engineering; **C. R. Turner**, Manager, Power Transistor Applications—LF/MF; **N. C. Turner**, Manager, Power Transistor Design—LF/MF; **H. Weisberg**, Manager, Thy-

ristor and Rectifier Engineering; and **R. L. Wilson**, Manager, RF Power Transistor Applications.

R. M. Cohen, Manager, Solid State Signal Device Engineering announced the organization of Solid State Signal Device Engineering, Solid State and Receiving Tube Division, as follows: **J. W. Englund**, Staff Engineer; **J. Hillibrand**, Manager, Device Technology—Bipolar; **I. H. Kalish**, Manager, Signal Device Model Shop; **R. R. Painter**, Manager, Digital Applications; **J. W. Ritcey**, Manager, Signal Device Consolidation; **R. A. Santilli**, Manager, Linear Applications; **L. R. Shardlow**, Manager, Engineering Services; **H. S. Valoric**, Manager, Device Technology—MOS; and **B. V. Vonderschmitt**, Manager, Circuit Design.

R. C. Pontz, Manager, Photo and Image Tube Operation, announced the organization of Photo and Image Tube Operation, Industrial Tube Division, as follows: **G. N. Butterwick**, Engineering Leader, Applications and Product Development—Image Tubes; **M. K. Massey**, Manager, Engineering and Manufacturing—Image Tubes; **J. C. Moor**, Engineering Leader, Image Tube Manufacturing; **A. F. McDonie**, Manager, Production Engineering—Photo Tubes; **A. G. Nekut**, Engineering Leader, Applications Engineering—Photo Tubes; **K. A. Thomas**, Superintendent, Photo Tube Manufacturing; and **E. J. Vresilovic**, Manager, Product Engineering—Photo Tubes.

M. B. Shrader, Manager, Power Devices Operations Department, Industrial Tube Division, appointed **F. W. Peterson** Engineering Leader, RF Cooking Tube Project.

C. W. Thierfelder, Manager, Engineering Department, Television Picture Tube Division, appointed **L. C. Ruth** Manager, EEC Picture Tube Applications Engineering.

T. E. Yingst, Manager, Power Devices Engineering, announced the organization of Power Devices Engineering, Industrial Tube Division, as follows: **J. J. Free**, Engineering Leader, Product Development; **F. G. Hammersand**, Manager, Super Power Devices Design Engineering; **H. E. Perry**, Manager, Super Power Devices Applications and Equipment Engineering; **J. R. Eshbach**, Manager, Electrical Equipment Construction and Maintenance; **J. B. Pyle**, Manager, Regular Power Devices Design Engineering; **R. A. Lee**, Engineering Leader, Product Development; **R. E. Reed**, Manager, Regular Power Devices Applications Engineering; and **C. E. Doner**, Engineering Leader, Product Development.

R. T. Rihn, Manager, Power Devices Manufacturing announced the organization of Power Devices Manufacturing, Industrial Tube Division, as follows: **E. L. Adams**, Manager, Testing; **J. J. Carroll**, Manager, Production Engineering; **E. F. Dinsmore**, Manager, Production Control; **D. G. Garbini**, Superintendent, Power Devices Operations; **C. Hanlon**, Superintendent, Power Devices Operations; **B. C. Houston**, Superintendent, Power Devices Operations; **H. E. Medsger**, Manager, Production Engineering; **S. B. Pickel**, Superintendent, Power Devices Operations; **R. A. Plourde**, Manager, Production Control; **H. W. Sawyer**, Superintendent, Power Devices Operations; and **B. Sheren**, Manager, Production Engineering.

M. Bondy, Manager, Receiving Tube Engineering, announced the organization of Receiving Tube Engineering, Solid State and Receiving Tube Division, as follows: **M. Bondy**, Acting Manager, Test and Special Products Engineering; **W. E. Kauf-**

Staff Announcements (cont'd)

mann, Manager, Receiving Tube Methods and Process Laboratory; **R. W. May**, Administrator, Engineering Administration; **P. L. Farina**, Manager, Special Products Engineering and Services; **R. N. Peterson**, Manager, Receiving Tube Applications; and **R. D. Reichert**, Manager, Receiving Tube Design.

H. K. Jenny, Manager, Microwave Solid State Devices Operation, announced the organization of the Microwave Solid State Devices Operation, Industrial Tube Division, as follows: **E. Goldman**, Manager, Solid State Devices Fabrication; **D. D. Mawhinney**, Manager, Product Engineering; **F. Sterzer**, Director, Microwave Applied Research Laboratory; **R. G. Talpey**, Manager, Subsystems Engineering; and **C. A. Vicari**, Administrator, Production and Project Control.

C. C. Simeral, Jr., Manager, Operations Services, Industrial Tube Division, appointed **H. A. Kauffman** to the newly-created position of Manager, Engineering Services.

J. J. Fencel, Manager, Tube Parts Manufacturing, Industrial Tube Division, appointed **J. J. Spencer**, Manager, Production Engineering.

W. H. Bliss, Manager, Plant Engineering, Scranton Plant, Television Picture Tube Division, appointed **T. R. Conway**, Manager, Plant Engineering Services. Mr. Conway will report to the Manager, Plant Engineering.

H. A. Kauffman, Manager, Engineering Services, announced the organization of Engineering Services, Industrial Tube Division as follows: **J. M. Forman**, Manager, Environmental, Special Equipment and Specifications Engineering; **J. K. Glover**, Manager, Standardizing; **J. W. Nauffts**, Manager, Electrical Measurements Laboratory; **S. A. Place**, Manager, Special Equipment Maintenance and Construction.

... PROMOTIONS ...

to Engineering Leader & Manager

As reported by your Personnel Activity during the past two months. Location and new supervisor appear in parentheses.

RCA Service Company

B. H. Morefield: from Associate Engineer to *Mgr., Radar—S* (M. J. Van Brunt, Cocoa, Florida)

Electronic Components and Devices

G. N. Butterwick: from Engr. Product Devel. to *Engr. Ldr. Product Devel.* (R. C. Pontz, Lancaster)

J. C. Moor: Engr. Manuf. to *Engr. Ldr., Manuf.* (R. C. Pontz, Lancaster)

J. B. Pyle: Engr. Ldr., Product Devel. to *Mgr., Regular Power Devices Design Engr.* (T. E. Yingst, Lancaster)

R. E. Reed: from Sr. Engr. Product Devel. to *Mgr., Regular Power Devices Application and Equipment Engr.* (T. E. Yingst, Lancaster)

J. J. Spencer: from Engr., Manuf. to *Mgr., Production Engr.* (J. J. Fencel, Lancaster)

William R. Percival: Adm., New Tube Type Planning to *Resident Engr.* (M. Bondy, Woodbridge)

Systems Engineering, Evaluation and Research

J. C. Shannon: from "AA" Engr. to *Ldr., Sys. Engr.* (T. M. Sheridan, Moorestown)

Missile and Surface Radar Division

W. L. Brenneman: from Proj. Admin. to *Admin. Engr. Operations* (G. R. Stevens, Moorestown)

J. Drenek: from "A" Engineer to *Ldr. D&D Engr.* (P. Levi, Moorestown)

J. J. Ratkevic: from "AA" Engr. to *Ldr., D&D Engr.* (M. Korse, Moorestown)

D. R. Billeter: from "AA" Engr. to *Môr. Prog. Mgmt. Staff* (W. H. Congdon, Moorestown)

G. C. Caldwell: from "A" Engr. to *Ldr., Engr. Systems* (W. H. Congdon, Moorestown)

Aerospace Systems Division

W. J. Gray: from Sr. Proj. Mbr. to *Ldr., T. S.* (D. M. Larson, Burlington)

A. Muzi: from Sr. Proj. Mbr. to *Ldr., T. S.* (A. Amato, Burlington)

R. J. Monis: from Sr. Mbr. to *Ldr., T. S.* (E. Stockton, Burlington)

A. H. Fortin: from Sr. Mbr. to *Ldr., T. S.* (E. Stockton, Burlington)

Communications Systems Division

B. Patrusky: from "A" Engr. to *Ldr., Systems Proj.* (C. Arnold, Camden)

B. E. Tyree: from "A" Engr. to *Ldr., D&D* (G. Kalkman, Camden)

Electronic Data Processing

B. W. Pollard: from Mgr., Product Planning to *Mgr., Engineering* (A. D. Beard, Camden)

Broadcast and Communications Division

E. D. Taylor: from "AA" Engr. to *Ldr., D&D Engr.* (H. S. Wilson, Camden)

COMPUTERIZED LOGIC SIMULATION

In response to the growing need within RCA for a logic-element simulator, DEP Applied Research has developed the LOGSIM (Logic Simulation) series of computer programs. Early versions of these programs were written in FORTRAN to maintain maximum availability on a range of computer systems. However, current releases of the program are being written in assembly language to achieve maximum operating speed and capability.

The latest released version of the program series, LOGSIM II, Rev. 1, provides the user with 16 basic logic-element models which span both bipolar and MOS technologies. User controls permit the system to report design timing errors which produce unwanted signals, and make specified comparisons between "actual" and predicted operation. These controls can also be used to provide complete tables of all interconnections, and to facilitate user formatting of the output data. The program structure is such that it eliminates large amounts of unwanted—steady state—output data while maintaining waveform integrity.

The current capability of the program, still in FORTRAN, is approximately 800 gates on a 131,000-byte 70/45 and 1500 to 2000 gates on a 262,000-byte 70/45. However, these gate capabilities will be increased in the next revision of LOGSIM.

The program is documented in a user's manual that has been widely distributed within the Product divisions. To date, LOGSIM training workshops have been held for ASD, CSD, M&SR, and DME. Production use is either in progress or scheduled to start at ASD, CSD, and DEP Central Engineering. Assistance to new user groups is available upon request from H. Zieper, Ext. PC 5071, or W. Clapp, Ext. PC 3094, Camden, N.J.

DEGREES GRANTED

- J. T. Grabowski**, Pr. Labs. MS, Physics, Univ. of Penna., 8/67
- S. A. Keneman**, Pr. Labs. MS, Electrical Engineering, Mass. Inst. of Technology, 6/67
- P. J. McGinley**, Pr. Labs. MBA, Business Admin., Seton Hall, 6/67
- A. Morrison**, Pr. Labs. MA, Geology, Boston Univ., 5/67
- R. Nosker**, Pr. Labs. MS, Electrical Engineering, Princeton Univ., 6/67
- L. C. Parrillo**, Pr. Labs. MS, Electrical Engineering, Princeton Univ., 6/67
- M. W. Sanders**, Pr. Labs. MBA, Business Admin., Seton Hall, 6/67
- L. Schein**, Pr. Labs. MS, Physics, Columbia Univ., 6/67
- J. B. Hayes**, Pr. Labs. LLB, Law, St. Johns Univ., 6/67
- R. A. Sunshine**, Pr. Labs. MA, Electrical Engineering, Princeton Univ., 6/67
- J. M. Laskey**, ASD MS, Engineering Mgmt., Northeastern Univ., 6/67
- R. T. Testa**, AED BS, Electronic Physics, LaSalle College, 6/67
- R. Baldwin**, AED MS, Systems Engineering & Operations Research, 6/67
- S. H. Fairweather**, AED MS, Business Administration, Seton Hall Univ., 6/67
- D. Gandolfo**, AT Ph.D., Physics, Temple Univ., 5/67
- H. Rangachar**, AT Ph.D., Electrical Engineering, Graduate School of Arts and Sciences, Univ. of Penna., 5/67
- B. Feingold**, AT MS, Physics, Univ. of Penna.
- H. Rosenblatt**, AT MSE, Moore School, 5/67
- P. Z. Peebles**, MSR Ph.D., Electrical Engineering, Univ. of Penna., 6/67
- C. Eubanks**, MSR BS, Univ. of Penna., 5/67
- M. W. Ichinaga**, MSR MS, Electrical Engineering, Drexel Inst., 6/67
- C. Specht**, MSR BS, Electronics Physics, LaSalle College, 6/67
- M. Pollock**, MSR MS, Electrical Engineering, Drexel Inst., 6/67
- F. A. Eble**, MSR MS, Civil Engineering, Univ. of Penna., 6/67
- L. W. Harlan**, MSR MS, Electrical Engineering, Drexel Inst., 6/67
- J. S. James**, MSR BS, Drexel Inst., 6/67
- M. J. Lutz**, MSR MS, Mechanical Engineering, Drexel Inst., 6/67
- H. C. Cox**, MSR BS, Drexel Inst., 6/67
- H. C. Goodrich**, MSR MS, Electrical Engineering, Drexel Inst., 6/67
- E. C. Horton**, MSR Diploma Electrical Engineering, Drexel Inst., 6/67
- G. Hyde**, MSR Ph.D., Electrical Engineering, Univ. of Penna., 6/67
- E. Staiger**, MSR BSE, PMC, Philadelphia, 5/67
- T. Strecki**, MSR BS, Business Administration, Rutgers Univ., 6/67
- R. V. MacBride**, MSR BS, Electrical Engineering, Drexel Inst., 6/67

PROFESSIONAL ACTIVITIES

Charles M. Odorizzi, RCA Group Executive Vice President, was awarded the honorary degree of Doctor of Science in graduation ceremonies June 12 at Florida Institute of Technology, Melbourne, Florida. He delivered the graduation address, "Science, Business and Education." In the class of 89 graduate and undergraduate students receiving degrees were 11 RCA employees. Mr. Odorizzi was cited for his "brilliant career in the advancement of America's business and industry".

Bernard Tiger of RCA Defense Electronic Products, Camden, New Jersey was chairman of a technical session on reliability prediction at the Sixth Annual Reliability and Maintainability Conference held in Cocoa Beach, Fla., July 17-19. **George Ashendorf**, also of DEP, presented a technical paper, "Pitfalls in Reliability Prediction", at the same session.—*J. R. Hendrickson*

D. R. Hill, Technical Operations Mgr., RCA Missile Test Project, has been appointed chairman of the industry relations committee for the Canaveral Section of the IEEE.

Astro-Electronics Division: **B. P. Miller**, Manager Earth Orbit Mission, and **Dr. E. deHaas** are Vice Chairman and Secretary, respectively, of the Princeton Section of the AIAA (July 1, 1967). Participating at the Summer Conference of the National Academy of Sciences at Woods Hole, Mass., are **S. Gubin**, Manager Space Communications Systems Engineering, **Dr. R. Marsten**, Manager Spacecraft Electronics, and **Dr. S. Spaulding** (June 15 to August 5, 1967).—*S. Weisberger*

RCA Laboratories: **Dr. Jan A. Rajchman** served as a member of the 12-member U.S. Delegation to the Meeting of the Popov Society (the Soviet equivalent of the IEEE) in Moscow from May 4 to 7, 1967. Although all fields of electronics were covered at the meeting, there was considerable emphasis on computers, particularly on time-sharing networks. Dr. Rajchman also visited several computer laboratories in Moscow and Leningrad.—*C. W. Sall*

SILICON POWER CIRCUITS MANUAL

The *RCA Silicon Power Circuits Manual*, SP-50, published by Electronic Components and Devices is the newest member of the growing family of RCA technical manuals. This 416-page manual provides design information for a broad range of power circuits using RCA silicon transistors, rectifiers, and thyristors (silicon controlled rectifiers and triacs). Design examples are given, and typical practical circuits are shown and analyzed. *The manual can be purchased from an RCA distributor or from Commercial Engineering, EC&D, Harrison, N.J.; the suggested price is \$2.00.*



NEW POST FOR C. W. FIELDS

C. W. Fields, Communications Systems Division, was appointed Administrator, Technical Communications. In this capacity he is responsible for the Camden Library and the Administration of Technical Publications for Communications Systems Division.

Mr. Fields is an RCA ENGINEER Editorial Representative and has been active in the planning and development of papers for publication in the RCA ENGINEER as well as in outside publications; he recently was responsible for coordinating Vol. 12, No. 5 which emphasized Advanced Communications.

C. W. Fields received the BS in Journalism from Temple University in 1955 and has since taken courses in electronics and technical writing. After work on local industrial periodicals, he joined RCA in 1956 as technical writer, later advancing to engineering editor, concerned with writing and editing a variety of engineering publications in DEP Communications Systems Division. In 1963, he was named Chief Editor, CSD Documentation and Engineering Publications. He created and helped coordinate the continuing "engineering lecture" series in Camden.



CREDIT TO H. J. RUSSELL

The Editorial Staff of the RCA ENGINEER extends its sincere thanks to **John Russell**, RCA ENGINEER Editorial Representative for RCA Victor Company, Ltd., for his active participation in editorial activities over the past eight years. John not only has served an active Editorial Representative and TPA for his division, but has also personally coordinated two separate issues of the RCA ENGINEER: Vol. 11, No. 6, devoted to Plasma Physics, in which many papers by RCA Victor research engineers were featured, and Vol. 13, No. 3, the current issue, devoted to communications satellites and ground stations and again featuring the accomplishments of the RCA Victor engineers. With this issue of the RCA ENGINEER, John is retiring from active work in engineering and is being succeeded as Editorial Representative and Technical Publications Administrator by **W. Chisholm**. The Editorial Staff welcomes Mr. Chisholm to his new activity. We look forward to his carrying on the activities well established by Mr. Russell.

H. J. Russell studied electrical engineering at Battersea Polytechnic, London, afterwards joining Marconi's Wireless Telegraph Co., Ltd., where he spent eight years in the design and development of ground and airborne communication equipment. He was then transferred to the Research Department where he worked on facsimile transmission over long HF circuits and the development of equipment for recording on steel wire and tape. His next appointment in the Marconi Company was to plan and develop the technical organization and equipment of Egyptian State Broadcasting in Cairo, Egypt, later becoming Engineer-in-Chief of this organization, a post he held until 1944. During the war years he planned and carried out a number of technical projects for the British Middle East Forces, being awarded a mention in dispatches for distinguished service. The last two years of the war spent in South East Asia as Technical Advisor to South East Asia Command on assignment to the British Foreign Office, where the work consisted of planning and supervising the buildup of telecommunication systems in liberated countries.

After the war, Mr. Russell was sent to Egypt to organize a Middle East office for the Marconi Company and act as technical representative. On completion of this assignment in 1949, he was appointed technical consultant to the Brazilian Marconi Company in Rio de Janeiro, where he reorganized the technical facilities. In 1952, he was seconded by Marconi's Wireless Telegraph Co., Ltd. to the British Commonwealth Relations Office for three years to act as Chief Technical Advisor to the Ceylon Government in reorganizing and re-equipping Radio Ceylon. He was transferred to the Canadian Marconi Company in Montreal in 1955 to organize and build up international export of their products. He joined RCA Victor, Ltd. in 1957 as Manager of Administration, Defense Systems Division. Mr. Russell is an Associate of the Institute of Electrical Engineers and the Engineering Institute of Canada.

RCA ENGINEER BINDERS AVAILABLE

Wire-rod-type, brown, simulated-leather binders are available for binding back issues of the RCA ENGINEER. The binders are 9 1/4 x 12 x 3/4, and will hold about 10 issues each. The magazines are held in place by wire rods (supplied) that run along the center fold of the magazine and snap in place (no need to punch holes or otherwise mutilate the issue). These binders may be ordered directly for two-week delivery as follows: Order by stock number and description *exactly as below*; make check or money order payable *directly to the vendor*, and specify method of shipment:

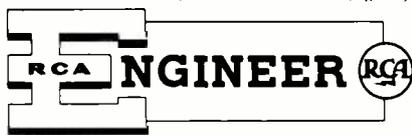
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GSD TO MOVE

The Graphic Systems Division is scheduled to move from Princeton, N.J. to its new facilities in Dayton, N.J. in October 1967. Ground was broken for the new 56,000-square-foot facility on Route 130 on May 12, 1967. The new building, which provides for substantial expansion, will initially house 260 employees and will use approximately 20 acres of the 101 acre site.—*J. L. Gold*

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FUTURE ISSUES

The next issue of the RCA ENGINEER emphasizes Integrated Circuit Arrays and Applications. Some of the topics to be covered are:

Impact of IC's in Engineering
Bipolar Arrays
Interconnection, Assembly, Packaging, and Reliability of IC's and Arrays
Planar IC's
Epitaxial Techniques
P-Channel Arrays
Complementary MOS Technology

Discussions of the following themes are planned for future issues:

Advanced Computer Technology
Broadcast and TV Communications
Graphic Systems and Devices
Automatic Testing
Man-Machine Alliances in Engineering
Electron Tubes: Conversion, Power, Color TV

^o Technical Publication Administrators for their major operating unit.



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