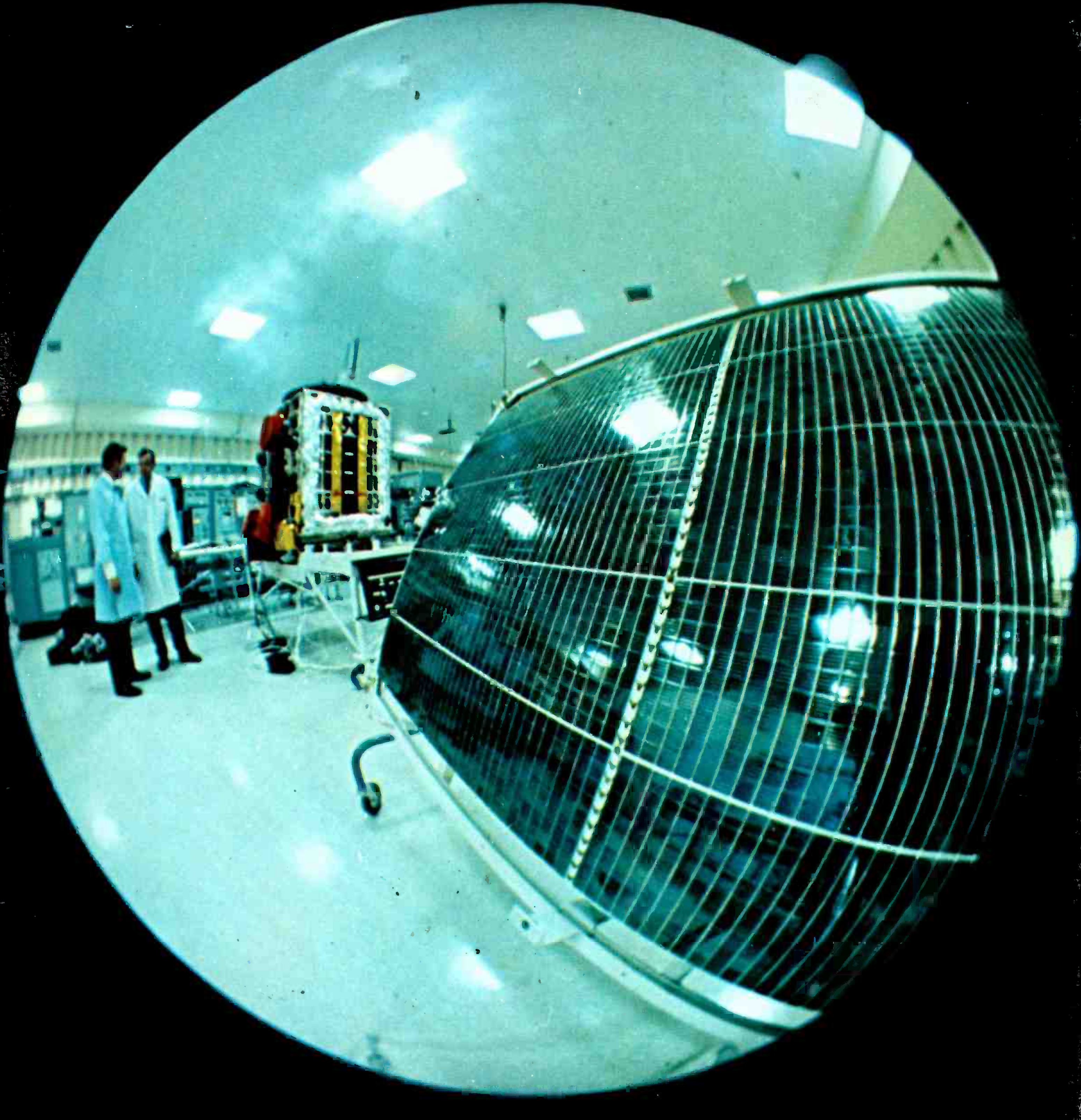
RCA Engineer

A TECHNICAL JOURNAL PUBLISHED BY CORPORATE ENGINEERING SERVICES
"BY AND FOR THE RCA ENGINEER"

Form No. RE-17-1

Printed in U.S.A.



RCA ENGINEER

VOL. 8, NO. 3

OCT.-NOV. 1962

# CONTENTS

## PAPERS

## NOTES

## DEPARTMENTS

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.*

Familiar to most product engineers is the *design review*, a formal program in which product designs are reviewed by committees of highly qualified engineers at significant milestones during the transition from concept to hardware. But, *why do we have such programs? What is the philosophy behind them?* And—most important—*what can engineers and engineering managers do to organize better design-review programs and then make them effective in a very practical sense?*

### WHY HAVE A DESIGN REVIEW PROGRAM?

One of the best ways I know to answer this question is to describe the circumstances under which the DEP Missile and Surface Radar Division in Moorestown, N. J., established its program. Just prior to the Korean War, this Division (then a department of only 75 engineers), started its rapid expansion in both size and scope. Search and tracking radars, gun fire-control systems and, later, missile-guidance systems constituted its product lines. The state-of-the-art in these systems was constantly changing and becoming more complex. At the same time, we had to depend, to a large extent, on a growing group of young, inexperienced engineers, a situation typical throughout the industry in those early days of defense electronics.

The Engineer and the Corporation

# THE DESIGN REVIEW

## . . . Effective Tool, or Red Tape?

**L. JACOBS, Mgr.**
*Design Support Engineering*
*Data Systems Division*
*DEP, Van Nuys, California*

You can probably visualize some of the problems that can occur during production, as a result of this situation. There were cases of parts being inadequately specified. While parts met the drawing requirements, performance varied as a function of uncontrolled parameters—for example, degradation of performance with time. Where parts were used too close to, or exceeding, their rated values, they failed prematurely. Circuits did not always meet specifications under worst-case conditions of part tolerance, line voltage, and environment. Mechanical designs were sometimes impractical to manufacture at reasonable cost, and parts didn't always fit when made to extremes of drawing tolerances.

One of the frustrating factors was that many of these problems did not show up in the first few production units, but often in the tenth, fifteenth, and even later units. Crash programs, with the most talented engineers working around the clock, had to be established to solve the problems. While the problems were solved, these "fixes" were expensive and usually could not be done in the most efficient way, because of the advanced stage of production. The over-all problem was not a lack of engineering design innovation or of basic engineering knowledge in the strict sense. Rather, it was one of harnessing the *potential* effectiveness of a *group* of design engineers so that a complex piece of finished hardware not only satisfied the customer but also met the profit objectives of the company.

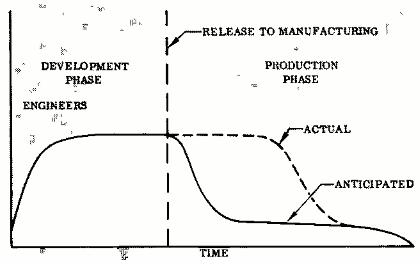


**Fig. 1 — Engineering effort on combined development program and production program—1950 to 1953.**

Fig. 1 illustrates, by the solid line, the normal engineering spending rate on a combined developmental and production program, where the design is straightforward and handled by thoroughly experienced engineers. It also shows, by the dotted line, the kind of spending rate that occurs under the situation that I have just described. Note the tremendously higher spending rate during the early part of the production phase.

Analysis of these production problems revealed that most of them could have been foreseen and avoided by proper design. The challenge was, then, to find methods to get better, more thorough designs under the unavoidably difficult conditions of tight — even extreme — time schedules, stiff reliability criteria, and technically complex systems and hardware. It was also obvious that our ability to develop more effective engineering methods under these conditions would have *great influence* on the share of future defense—electronics business that we could hope to command. The concept of *meaningful design reviews* was one important approach.

### EARLY APPROACHES TO DESIGN REVIEW

We studied this problem exhaustively during those years and considered solutions that might be thought of as obvious, or straightforward. One of these would be to get "better" engineers and train them more thoroughly. Our study showed, however, that our selection techniques were good and our engineers were at least as capable as the industry average. Furthermore, at least 50 percent of them were going to school at night for advanced degrees, and we were already running many RCA-sponsored classes at the plant on specific subjects directly related to our product line.

We stressed on-the-job training, setting up key senior engineers to assist the younger ones. But, with the pressure on the senior ones to handle their own design responsibilities, this effort was obviously not the total answer. We emphasized the technical responsibilities of the first-line supervisors, chosen for their technical as well as their managerial ability; but, they had neither the over-all technical breadth nor the time to review designs in sufficient detail to find most of the potentially serious problems.

We recognized that these problems *would not* solve themselves with time, for two reasons: 1) we had every reason to believe that the state-of-the-art would continue to advance rapidly and 2) the industry would continue in its high growth rate and therefore, we could anticipate a continuing influx of young, inexperienced engineers. So, in 1953, we took our first step towards design reviews by assigning one electrical design engineer and one electrical parts engineer to independently review certain designs. The potential problems picked up were significant, but we couldn't spare more people from their regular design assignments to extend the scope of this program. So, we established "area coordinators" within each design group to police themselves. But this proved only partially successful for several reasons: 1) the coordinators had their own design responsibilities, 2) they weren't trained in the techniques of conducting design reviews, 3) they had a tendency to hold back in criticism of the designs of their associates, and 4) they tended to yield to pressure from their own managers to "get the job out".

Recognizing that the use of area coordinators would not do the job we wanted, emphasis was placed on building up an organization of design review engineers that could handle all design reviews, using expert technical assistance from other groups only in specialized fields. The design review activity in this Division gradually increased in size and responsibility until 1958, when it reached what is essentially its present form. Growth and consolidation of effort has continued since then, and experience has led to solution of many of the early problems with the design review.

### ORGANIZATION FOR DESIGN REVIEW AT DATA SYSTEMS DIVISION

The organization and operating principles of a design review activity can best be explained by describing a specific situation; in this case the organization in the DEP Data Systems Division, Van Nuys, Calif. This division was formed in the spring of 1959 from a nucleus of about 120 engineers and managers from the Missile and Surface Radar Division in Moorestown, N. J., and a somewhat smaller number from the existing Los Angeles plant. Our organization, shown in abbreviated form in Fig. 2, was patterned after that of Moorestown.

Two project groups handle the business management of all projects, prepare and issue specifications for the contractual items to be supplied, and coordinate the system test and installation and checkout in the field. Systems Engineering provides the systems studies of new concepts that lead to new development projects and also optimize the systems of the projects in the house to assure delivering the most up-to-date and reliable equipments possible within the state-of-the-art. Engineering Support Services handles facilities, budgets, instruction manuals and spare parts provisioning and logistics. Design and Development is functionally organized to maximize the use of engineering talent and facilities. Note that Design Support Engineering, the group responsible for design reviews, reports *directly to the Chief Engineer.*

Fig. 3 shows the organization of Design Support Engineering with emphasis on those activities having design review responsibilities. Electrical design review is covered by the Electrical Design Methods' engineers, who also provide circuit-design consultation and reliability studies. Mechanical design reviews are covered by the Mechanical Design Methods engineers who also coordinate the mechanical design of widely used items such as modules, chassis, and cabinets. The other two groups making up Design Integration provide the support on parts, materials and processes, during the design review phase as well as, of course, during the design engineers' part selection phase.

### WHAT KIND OF ENGINEER FOR DESIGN REVIEWS?

The engineer who performs design reviews must have high skill and broad experience in the design of the product he reviews. Moreover, he must have certain characteristics *not often found* in the average good design engineer.

First, he must, in some instances, be able to suppress his creative instinct and examine the designs from an objective standpoint of: "Will the design meet the specification, have the desired reliability and be economical to manufacture—*even though I might not take this approach myself?*" Most engineers, upon examining a design, set their minds to work and come up with new approaches to do the job. Perhaps they are better ways, but usually they are just different ways. Only after the design has been completely studied *and* found wanting should the design-review engineer recommend alternative approaches.

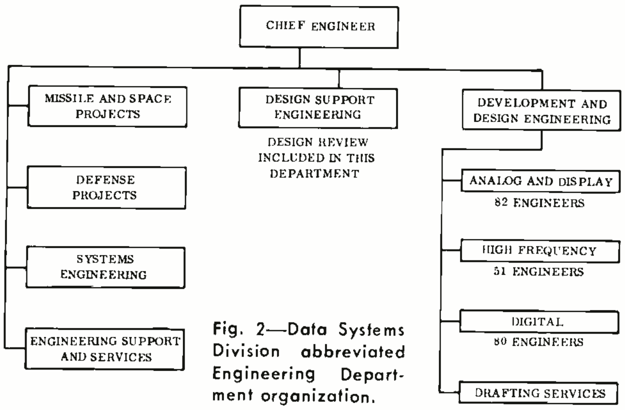


Fig. 2—Data Systems Division abbreviated Engineering Department organization.

Second, he must find satisfaction with indirect, rather than direct, contributions to the product design. Most engineers like to start with the concept, proceed through development and test, ending with a model that can be seen, felt, and pointed to with pride as their creation. The design review engineer knows that he has contributed something to many designs but there may well be no drawings he has signed and no hardware he has sweated through a shop.

It is difficult to find the right engineer for design review. Those who qualify are usually busy on hot jobs and their managers are naturally concerned about jeopardizing project success if such men are removed from direct engineering work to serve in the review capacity. But engineering management must recognize the long-run benefits so that only fully qualified engineers are members of the design review team.

Recognizing that the creative engineer needs an outlet for his talents that may not be fully satisfied by reviewing designs, it is important to spice the design review engineer's assignments with short-duration, but critically important, design tasks. Such arrangements have the additional salutary effect of elevating the stature of the design review engineer in the eyes of the design and development engineers. Also, since many otherwise qualified engineers do

L. JACOBS, graduate of Columbia University, received his BSME in 1937, and MSIE in 1938. He joined RCA in 1939, and spent his first four years in the Manufacturing-Engineering activity. In 1944, he joined the Engineering Department where he was assigned to mechanical design of ground based and shipborne radars. This was followed by his designation as the Mechanical Project Engineer of an advanced precision automatic tracking radar. He continued mechanical engineering with increasing coordination responsibilities for all mechanical design on ground based and shipborne radar until 1952. He was then promoted to Manager, Mechanical Engineering, for the Missile and Surface Radar Department, where he directed a rapidly growing activity that expanded its operations to include complete missile guidance systems. The mechanical-engineering efforts covered, in addition to the usual mechanical design of electronic equipment, the design of servomechanisms, microwave plumbing, antennas up to 84 feet in diameter, hydraulic drives, optical devices, towers, radomes, trailers, shelters and missile handling and launching equipment. In December, 1958, Mr. Jacobs was assigned to manage the Design Support Engineering group, an activity that includes electrical and mechanical parts application, review of all designs from the standpoint of performance, reliability and maintainability, value engineering, drafting coordination, mechanical development coordination, the model shops, and other design support services. In August, 1959, Mr. Jacobs was transferred to the newly established Data Systems Division to organize a Design Support Engineering function similar to the one he managed in Moorestown. He has continued to manage this activity with its increasing responsibilities in reliability and associated functions.

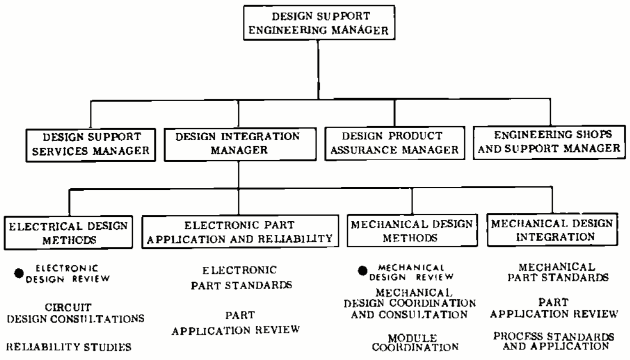


Fig. 3—Design support engineering organization.

not want to make design review their career as such, arrangements have been made for yearly rotations.

### MAKING THE DESIGN-REVIEW PROCEDURE WORK

**Costs**—The efforts of the design review engineers are considered direct labor, chargeable to the contract. Therefore, estimates are prepared for each "Request for Bid" received. Separate shop orders are established to accumulate costs incurred and control is in the hands of Design Support Engineering management. Thus, when the profit picture looks bleak, this essential activity is not cut back as readily as other overhead activities in often necessary short-run adjustments in operating expenditures.

**Schedules**—Each identifiable, deliverable item is scheduled from concept to final test. Significant design review milestones during its development are established jointly by the supervision of the design and development group and the design review group. Job progress with respect to schedule is reviewed by design and project management for assurance that these reviews are not bypassed in an effort to make up time lost for other reasons.

**The Design Review Committee**—The engineers in Design Integration cannot possibly have the diversifications of talent to review in depth the wide variety of electrical circuits, computer logic, electromechanical devices, and packaging concepts found in this rapidly changing electronics industry. Therefore, we must call upon technical experts from the design and project groups (and sometimes from outside the division), to supplement the talents of our people. The chairman, chosen by Design Methods' supervision, can choose the committee members from lists of technical experts prepared by the engineering group managers. (Approval for each specific assignment must, however, be granted by each man's immediate supervisor.)

Other members of the committee are the responsible design engineers, their immediate supervisors, and the project engineers. Also included, depending on the nature of the design being reviewed, are parts specialists, systems engineers, human factors engineers, reliability coordinators, and manufacturing process engineers.

**Types of Reviews**—Of prime importance in the review series is the specification review. I have seen many man-years of effort lost because specifications were not clear, complete, and concise. It takes relatively little time, *but a lot of good thought,* to review thoroughly a specification to assure that what is written is what is really wanted.

When the specification covers an equipment to be designed by another RCA Division or a subcontractor, the design review committee reviews it prior to submission for quotation to prospective suppliers. Except where it covers an unusually complex, highly developmental device, the specification on an equipment designed in the Data Systems Division is reviewed along with the review of the design group's concept for meeting the specification.

For electronic designs a *Concept Review* is held as soon as the block diagram and principal schematics have been prepared, but just prior to making breadboard models. A *Major Review* of the circuit design is held after tests are complete on the breadboard model. A *Final Review* is held at the completion of the engineering model testing or subsequent testing, as applicable.

For mechanical design a *Concept Review* is held as soon as the drafting layout is sufficiently complete to define the design engineer's approach. A *Pre-Sign Off Review* is held when the drawings are complete but prior to release, for fabrication of the engineering model. A *Major Review* is held after completion of the engineering model or subsystem. When large quantities are involved, a *Final Review* is held prior to release to Manufacturing.

Other reviews are held on logic designs, electromechanical equipments and other items that are not clearly either in the electronic or mechanical design categories. The combination of talents best suited for the particular device is chosen to constitute the committee.

**Preparation For The Design Review**—Probably the most valuable part of the design-review process is the design engineer's preparation of his material for the review. Knowing that his work will be examined critically by experts he endeavors to be certain that his design is right. Using checklists prepared by the Design Methods group, he reviews his own design as he prepares his material, and more often than not, finds weak points that he corrects prior to review —or presents at the review his plans for correcting them.

There is nothing quite as satisfying to a design engineer as coming through a design review "smelling like a rose" with few and minor modifications recommended.

**Conduct of the Meeting**—Earlier in this paper I mentioned some of the characteristics required of a design-review engineer, emphasizing the need for objectivity and the suppression of the tendency by the creative engineer to promote other ways of doing the job which may or may not be better. Unless the recommendations are obviously and significantly superior to the approach taken by the design engineer, no consideration should be given to alternative approaches. The committee members, after having studied the material prior to the review meeting, should point out where the design does not meet the specification from the standpoint of performance, reliability, maintainability, manufacturability, availability of parts and materials and, of course, cost.

Frequently, the design engineer admits the desirability of a recommendation, but states that he cannot include it because of the additional engineering time and cost involved. The project engineer, knowing the over-all system schedule and the financial condition of the contract, can frequently authorize the additional effort at the meeting. If not practical to do so at this time, he investigates the practicability of doing so after the meeting.

**The Design Review Reports**—The committee chairman prepares a report to the manager of the responsible design activity, covering the committee recommendations. The design engineer must indicate, on the same report, his action on the recommendations. Copies are distributed to all committee members plus key people in Projects, Design and Development, Design Support Engineering and Product Assurance.

**Resolving Problems**—A fundamental principle that must be observed in this program is the maintenance of design responsibility with the design engineer. *The committee can only recommend.* But by virtue of the position in the organization of Design Support Engineering and the technical competence of the committee, most recommendations are accepted. When the committee chairman feels strongly that the design engineers' reasons are inadequate and that the effect on the design will be serious, he and his immediate supervisor try to resolve it with the design engineer's supervisor. If they do not succeed the problem is taken up through line supervision to the Chief Engineer.

In the Data Systems Division's history of over three years, it has not been necessary to go to the Chief Engineer. This does not mean that all problems were resolved to the satisfaction of the Design Methods group; rather, it does mean that the decision depended upon opinions that required extensive investigation of alternative approaches for which time or money was not available.

### EFFECTIVENESS OF THE DESIGN REVIEW PROGRAM

Like education and training, the effectiveness of a design review program is difficult to measure. A casual examination of the reports reveal that most recommendations appear minor or even picayune. And perhaps they are. But this should be expected because most design engineers are responsible and capable, and we have supervision training and support groups to assist them. Moreover, as mentioned previously, the preparation for the design review provides a self-policing effort that reveals potential design faults. However, there are still a significant number of potentially serious problems revealed during design review and alternative approaches provided that we feel confident that the program more than pays for itself, even if we use only *money saved* as the yardstick.

We have enough specific examples of cost-saving design recommendations that alone could almost pay the program's running expenses. When one adds the customers' savings in the form of reduced maintenance, the savings are significantly higher. We cannot overlook either the incalculable savings in the form of improved delivery (by minimizing production problems), improved reputation with customers, and training and evaluation of engineers.

Let us return to Fig. 1, showing engineering spending rate during a combined development and production program. Although we continue to have a high percentage of relatively inexperienced engineers and a rapidly changing state-of-the-art, our spending rate curve has gone back to the shape it had when we designed simple "black-box" type equipment with a small number of experienced engineers. Another measure of the effectiveness of design review is the fact that observed reliability exceeds that calculated by such accepted methods as those described in *RADC Notebook TR-58-111*, Section 8.

### THE DEPARTMENT OF DEFENSE AND DESIGN REVIEW

Following the release of the Department of Defense report *Reliability of Military Electronic Equipment* prepared by the Advisory Group on Reliability of Electronic Equipment (AGREE), in June 1957, the Government has stressed reliability in its contracts. Equipment specifications have invoked quantitative reliability requirements. Reliability specifications now state requirements for organization, techniques, programs, tests and reports. *One of the techniques invariably required by these specifications is design review.* Thus, the Department of Defense has recognized the value of design review and is requiring its application.

### ESSENTIALS OF ORGANIZATION FOR DESIGN REVIEWS

The following are the points that I think are essential in organizing for design review:

*Gaining Management Support*—If the ultimate responsibility for the design is to remain in the hands of the design engineer, as I think it should, top management support is essential to the program's success. To gain this support, those concerned with design reviews must conduct their activities and present their findings *effectively*, so that good recommendations submitted through line supervisors do not fall upon deaf ears—for if they do, the design review program is doomed. To avoid such frustration, the good design review engineer must apply his creative talent just as vehemently as he would in seeking hardware innovations.

*Organization Separate From D&D Reporting To The Chief Engineer*—Although it may seldom be necessary to do so, the design review engineer must know that he can appeal to the top if he feels his case warrants it. Knowing that this is possible, the design engineer will consider more seriously the committee recommendations and not lower the *not-invented here* barrier. This is analogous to the philosophy which requires quality control to report to top management through channels parallel with production.

*High Level Engineers*—Although seriously in demand elsewhere, top-level engineers must contribute to this program. Rotation of some, but not all, of the engineers from design and development to design review is practical and essential.

*Clear Cut Procedures*—Design reviews involve most activities in the engineering department. The responsibilities of each, as well as the detailed procedures, must be clearly defined and understood by the design review engineer to assure smooth integration of the review in the equipment development cycle.

*Formally Scheduled Design Reviews*—Schedules, generally prepared by the design or project activity, must include the specific reviews planned for the project. Management review of job status must include discussion of design review and must prevent exclusion of design review in an effort to make up time lost during development.

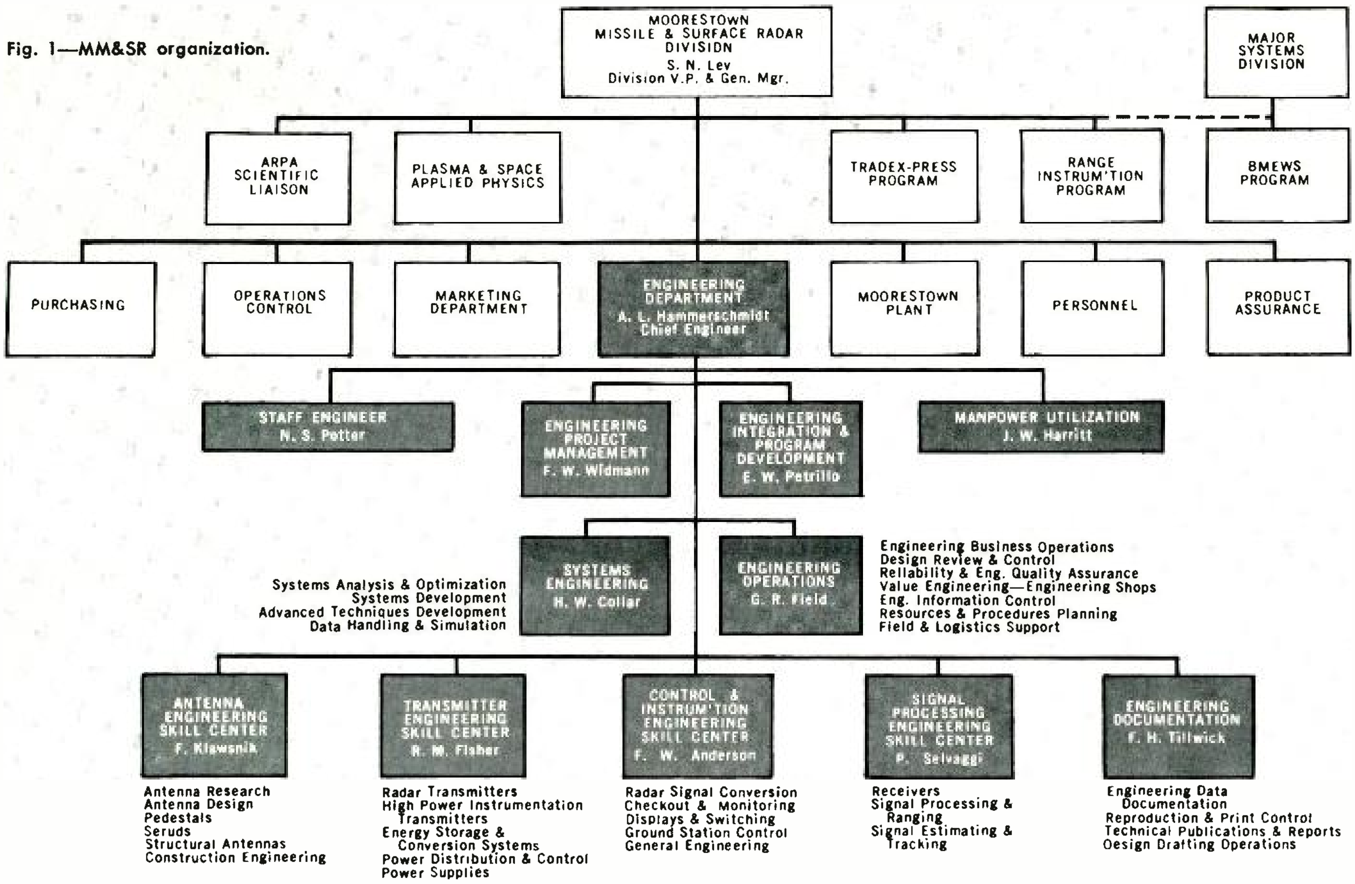
*Formal Reports With Responses To Recommendations*—The report serves to inform design groups of the review results so that action can be taken to investigate and act upon the committee's recommendations. It further serves as a source of information for subsequent reviews, frequently handled by different people. And, of course, it is essential in following up to assure implementation. Obviously, this again places a special demand on the design review engineers to take special care in reporting—in short, to communicate accurately and effectively, and not just to create paper to justify their existence.

### CONCLUSION

I hope I haven't given the impression that a design review, in the Data Systems Division, or anywhere else, will run perfectly, smoothly, and be wholeheartedly accepted by all engineers. This will never occur. It requires continued vigilance on the part of the design review activity to resolve problems as they occur and to continue to "sell" the program at every opportunity by conducting it most effectively.

Forecasts by the best prognosticators in the electronics industry indicate no diminution of the expansion rate in either size or complexity for many years to come. This is true of the aerospace industry, and many allied industries for which electronics are only part of the required hardware. Therefore, I look forward to a continuous expansion of design review methods and programs *as an integral part of the engineering process.*

Fig. 1—MM&SR organization.



# MM&SR ENGINEERING PHILOSOPHY AND ORGANIZATION

The theme of this issue is "Microwave Systems, Antennas, and Devices." The diverse scientific and engineering interest and capabilities so necessary to RCA's success in this important field exist throughout the entire corporation. Within Defense Electronic Products, the Antenna Engineering Skill Center in Moorestown has the major responsibility in the microwave and antenna field, and several papers in this issue were written by engineers from that activity. This article describes how the various engineering capabilities within MM&SR are employed to form an effective, well-integrated engineering team.

**A. L. HAMMERSCHMIDT, Chief Engineer**

*Moorestown Missile & Surface Radar Division*

*DEP, Moorestown, N. J.*

The basic organizational structure of the MM&SR Engineering Department is shown in Fig. 1. The management concepts and organizational philosophy that were used as guidelines in determining this structure however, are not evident from the chart alone. The rationale for the Skill Centers, the centralized business operations, and a consolidated Engineering Documentation activity, and the role of Engineering Integration as well as the implementation of the Project Management concept are important in understanding the organization structure.

### THE SKILL CENTER CONCEPT

The four Engineering Skill Centers shown on the bottom line of Fig. 1 represent a consolidation of talents devoted to a particular type of equipment or skill. Each of the Skill Centers has been established to constitute a major concentration of engineering capabilities in a given field by integrating all the technical and engineering skills necessary—from research through fabrication—to achieve a flexible product capability in a complex competitive field. As is evident from the titles of these activities, they are established on a functional basis and constitute an organizational entity devoted to the development and design of equipments identifiable as subsystems. The manager of each engineering skill center is responsible not only to fulfill those requirements placed upon it by Project Management activities, but also to develop product lines within its area of capability. Although their prime responsibility is that of developing the subsystems required for integration into large-scale systems, the fact that they are organized on a specialty basis provides the environmental stimulus necessary for the evolution of new product lines. Working through his respective Marketing manager, the Skill Center manager obtains contracts for studies or equipment in his specialty, enabling him to fill in that work load necessary for stability and growth.

The 7th Anniversary Issue of the RCA Engineer, Volume 8 No. 1, contains a descriptive report of the accomplishments of one of these centers, the Antenna Engineering Skill Center of MM&SR. This description of the work and achievements of the group shows the wide variety of work being done in all areas of the microwave and radio-frequency fields in radar, space communications, and satellite telemetry. The MM&SR microwave and antenna articles in this issue provide additional examples of the variety of work encountered. This

**A. L. HAMMERSCHMIDT** received a BEE degree from Ohio State University in 1938. From that time until he became associated in an executive capacity with NBC, New York; he was: Technical Supervisor for the Ohio State University radio station; a transmitter and development engineer for NBC, New York; and Supervisor of TV Technical Operations, NBC Cleveland. In 1952, an Assistant Director, Color Television Systems Development, he was responsible for operation of NBC's experimental color facilities in New York. In 1954 he became directly responsible for television operations and maintenance for the NBC network, New York City. He was also responsible for liaison with NBC and RCA engineering departments concerning the design and development of new equipment and facilities. In 1955, as Vice-President and Chief Engineer, NBC, he was responsible for design, development, and installation of all NBC technical facilities. From 1956, as Vice-President, Engineering and Facilities Administration, his activities included responsibility for NBC real-estate activities as well as architectural design, construction, and operation of NBC's physical plant. In March 1961, he was named MM&SR Chief Engineer. He is a Sr. Member of the IRE, and a Member of the SMPTE and Eta Kappa Nu.

variety is typical of the diversity of work in each of the Engineering Skill Centers.

### CENTRALIZED DOCUMENTATION

Recently established to operate in the same mode as the four Engineering Skill Centers is the Engineering Documentation organization, which brings together a concentration of skills and talents essential to the successful performance of engineering business. These talents must be applied, however, to work originating in each of the skill centers and required on each contract and program. Engineering Documentation brings together all engineering data documentation, design drafting operations, reproduction and print control, and technical publications and reports.

Centralization of these functions in this activity recognizes the importance of the "software," the counterpart to deliverable hardware. This recent change in organization is the result of two factors: 1) the increased emphasis which military customers are placing upon this area, and 2) the important part which uniform policy, procedure, and practice in the area of documentation contributes to Engineering Department efficiency. Standards and uniform methods of operation in drawings, parts lists, and instruction books are needed to satisfy military customers. Sufficient flexibility must exist to permit adjusting the extent of documentation required in support of special requirements or "crash" tasks. This organization recognizes the role that controlled, but selective flexibility plays in economical design and production, as well as timely delivery of quality-assured and -controlled products.

### SYSTEMS ENGINEERING

The Systems Engineering activity is comprised of a group of extremely capable senior engineers who provide systems engineering guidance for the Division, in both the generation and analysis of new systems concepts, in developing these systems to the proposal stage, and in support of contractual efforts. System analysis and optimization is accomplished in synthesis, analysis, and simulation studies prior to obtaining business, through interpretation of customer's specifications, and is conducted as a part of attaining the proper systems configuration throughout the entire development and design cycle. These systems engineers act as consultants and advisors during the development of hardware for a customer. They also develop new business potential and ideas.

Many major programs, such as DAMP, and others, entail the continued operation and use of RCA-built equipment to gather data of vital use to the customer. The Data Handling and Simulation Group of engineers and programmers analyzes, processes, and provides reports based upon these data. Simulation techniques, both analog and digital, permit the testing and evaluation of equipment and system performance prior to committing systems or designs for reduction to hardware. Two large-scale digital computers and an analog computer are available within MM&SR to carry out these studies. Other scientists and engineers in Systems are conducting development work in electronics and physics—advancing the state-of-the-art, and keeping abreast of research conducted throughout the corporation that applies to MM&SR products.

### ENGINEERING OPERATIONS

Engineering Operations provides those integrated and administrative services necessary to the efficient operation of the Engineering Department. This activity provides the engineering services and technical coordination functions, such as design reviews, reliability and value engineering, configuration control, engineering releases and change notices which are required by all the Engineering Skill Centers and on all projects. The engineering shops with the proper scheduling and quality control of their performance are included. In general, field and logistics support of all MM&SR equipments are centralized in this organization and contracts for depot operation, spares and major overhauls are assigned here.

Administrative services for the Engineering Department are also centralized in this function. The planning and control of engineering resources, such as manpower, facilities, test equipment, the engineering library, operating budgets and expenses, and Engineering Department operating procedures are provided.

The role of the centralized Business Operations function, which is a part of Engineering Operations, will be discussed in detail later.

### PHILOSOPHY OF ORGANIZATION

As pointed out by A. L. Malcarney, Group Executive Vice President, DEP and EDP, in the "Outlook for DEP" (Aug.-Sept. 1961 issue of the RCA ENGINEER), " . . . *Increasingly, the customer demands that sole responsibility for project performance be vested in a single Project Manager of stature, so placed in the organization that he can make or obtain decisions rapidly. We will locate our projects organizationally so that the Project Manager will be reporting to the level most appropriate for the resolution of problems which may arise. For example, if a program is primarily R&D in nature, the Project Manager will report to the Chief Engineer who can iron out issues which may arise among the engineering sections. If a program involves engineering and manufacturing within a division, the project manager will report to the Vice President and General Manager.*" This concept has been further explained in recent issues of TREND.

From Fig. 1, it can be seen that two such Project Management organizations, reporting to S. N. Lev, Division Vice President and General Manager, MM&SR, are established in Moorestown. In addition to these, the BMEWS organization and various other programs developed by the DEP Major Systems Division (also located in Moorestown), place work scopes in the MM&SR Engineering Department. These Project Management organizations provide the management, technical liaison with the customer, project engineering, scheduling, and cost control—and coordinate the manufacturing, engineering, and other line functions necessary to deliver the product to the customer. The engineering talents for the development and design of the individual equipments comprising these systems are provided within within the Engineering Skill Centers.

There is also a Project Management activity within the Engineering Department that has responsibility for programs which, for a variety of reasons, do not report directly to the Division Vice President and General Manager. The Engineering Project Management organization operates in the same manner as the Division Project Management organization, placing work scopes in the appropriate Engineering Skill Centers and developing extensions to existing business. The responsibility for program management for the Downrange Antiballistic Measurements Program (DAMP), previously described in the RCA ENGINEER, is an example of this sort of effort.

To provide the flexibility necessary for crash programs, such as the AN/TPS-35 radar, it is sometimes required that a "task force" be established for the duration of the job. Such a group within Engineering Project Management combines Project Management and all engineering in a single organization for the duration of such a task. In addition, the engineering and technical liaison with the customer necessary for certain production contracts, in which the R&D phase is completed, is provided by Engineering Projects Management.

## OPERATIONAL PHILOSOPHY

An over-all integrating function is necessary with an organization of the size and complexity of the MM&SR Engineering Department to assure cohesive and coordinated performance in concert with the Project Management concept. Although the Engineering Department is organized on a functional basis, certain services and talents need to be applied across the entire organization. Furthermore, some means of evaluating the over-all performance of the department is needed. Two organizational groups are established to implement effective integration: Engineering Operations and Engineering Integration & Program Development.

The Business Operations activity of Engineering Operations provides a very effective integration of the financial and schedule performance of the Engineering Department. Although centralized, Business Operations overlays all functional activities of the department and provides engineering managers at all levels with the support they need for sound decisions and effective cost and schedule performance. Centralized direction of business operations is provided through business managers assigned from this organization to each engineering activity manager and supported by an adequate staff of cost analysis, schedule, and clerical personnel. Thus, each engineering-activity manager has a counterpart business-operations manager who provides complete planning, scheduling, and cost data and analysis to the engineering manager. These business-operations personnel report to a manager of Engineering Business Operations, thus providing a unity of performance and standard methods throughout the department. The business operations organization is, in effect, superimposed upon the congruent Engineering Department organization. This reporting concept and uniformity of business action provides a very effective method of reviewing the overall performance of the organization.

Another extremely important feature of the organization is the Engineering Integration and Program Development function, which provides management with an overall picture of the performance of the department. The manager of this group acts as a deputy Chief Engineer, reviewing, monitoring, advising, and taking action when necessary, to assure that Engineering fulfills its obligations of technical performance, cost, and schedule to the Project Management organizations—as well as to anticipate potential problems and initiate effective corrective action. This function, therefore, enables the Chief Engineer to know what his obligations are, how they are being changed, and to control the resources of the Engineering Department.

The administration of MM&SR's advanced research and development program, as well as the review of all technical reports, papers, and presentations, is handled in this function.

The Program Development activity in this area is responsible for certain new business proposals. The Vice President and General Manager assigns responsibility for new business proposals. Those which are a direct outgrowth of an existing program, or represent systems best handled by an existing Program Management organization would be assigned to that Program Manager for preparation. The proposals for new programs not readily categorized into existing organizational units are assigned to the Program Development activity for preparation. Frequently, a proposal "task force" is established within this activity for duration of the proposal effort. New business obtained as a result of these efforts would not be assigned to this organization, but placed where appropriate within MM&SR.

## SUMMARY

It is evident that in addition to the normal line organization of the Engineering Department, both the Engineering Integration and Engineering Operations functions are established to assure an over-all integrated approach for the many projects being handled simultaneously within the Department. These superimposed integrating functions do not alter or dilute the authority and responsibility of the line-activity managers; rather, they supplement and aid him in fulfilling his obligations.

It is also evident that responsibility for conducting business within MM&SR is placed upon several levels consistent with the nature of the business:

**Division Responsibility.** Project management at the Division level generally handles large-scale systems programs involving many radars, computers, communication links, etc. as subsystems. *Examples:*

- TRADEX-PRESS
- Range Instrumentation
- BMEWS

**Engineering Department Responsibility.** *Engineering Project Management* handles projects assigned to the Engineering Department involving several subsystems, generally of a lower dollar volume than Division programs. Also, the Department is responsible for relatively small projects, either R&D or production, that require a small integrated task-team approach—generally involving a few up to 20 or 25 engineers. *Examples:*

- DAMP
- Tactical Radars AN/TPS-1 and AN/TPS-35

*The Engineering Skill Centers and Systems Engineering.* In addition to support of Project Management Programs, the individual Engineering Skill Centers and Systems organizations build product lines through obtaining direct contracts for jobs wholly within their specialty. Systems is responsible for the development of new concepts and ideas related to the MM&SR charter and in so doing, obtains and conducts system study contracts, and new techniques developments. These assignments, including inter-division transactions, are "project managed" within the appropriate group. *Examples:*

- Wideband Exciter (for Rome Air Development Center)
- Integrated Tracking and Communications System
- Electrode-less MHD Generator Research Study
- Radar Signal Correlation Techniques Study

The MM&SR Engineering Department, as organized to apply the concepts described herein, and implementing the Project Management method of doing business, provides the capable, efficient, well-managed team *we must have* in today's complex and competitive military electronics market.

# DESIGN PRINCIPLES OF SATELLITE-BORNE ANTENNAS

Although small and seemingly simple, a satellite's antennas pose challenging design problems. These include the conditions imposed by the physical parameters of the vehicle and of the orbit, as well as the nature of the transmission. Also of primary significance are the extreme environmental conditions of both launch and orbiting. Some types of radiators are discussed, including the approaches used for TIROS and RELAY.

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Once an active satellite is in orbit, contact is maintained with the earth through radio communications. Thus, commands to alter the mode of operation, perform required tasks, transmit acquired information or measured data, and relay information from one point to another all rely on the communication equipment and its antenna system. All probing from earth for position or velocity information depends upon the proper functioning of antenna elements on the satellite as well as those on the ground antennas. The latter sometimes receive greater prominence because of their large and massive configurations; but, the satellite antennas are no less challenging in spite of their smaller size and seeming simplicity.

### REQUIREMENTS AND LIMITATIONS

Antennas requirements are a function of the design parameters, conditions of orbit, location of ground terminals, required period of contact to each, the frequency and power of the transmission, and the type of data or information to be transmitted.

Early satellite orbits were at low altitude inclined to the equator. Stabilization was either nonexistant or simply space-stabilized by gyroscopic-spin techniques. As the complexity of the vehicles and sophistication of their uses increases, the types of stabilization will change; stabilization can be accomplished with respect to the earth's magnetic field, with respect to the earth's gravitational field, or with respect to a self-contained platform.

For many uses, a completely spherical radiation pattern would be ideal so that communication could be maintained without regard to orientation of the satellite. Such a pattern does not appear feasible, even in theory, for an electromagnetic radiator. With linear polarization there will be at least two nulls and with circular polarization at least one null to be tolerated. The loss of coverage caused by a null in the pattern is shown in Fig. 1; this shows the percent area of the full sphere not covered for various angular widths of the null cone. For a 99.9-percent coverage, the cone angle must be less than 7°. When the pattern is omnidirectional or doughnut-shaped there will be two nulls. Because the patterns are less than full-sphere coverage, the gain value will be connected with the directivity. The gain of a doughnut-type pattern is shown in Fig. 2 as a function of coverage angle or beamwidth. Gain is approximately 1 db over an isotropic radiator when the omnidirectional pattern covers an angle of 100°.

Fig. 1—Lost coverage resulting from a null in the pattern.

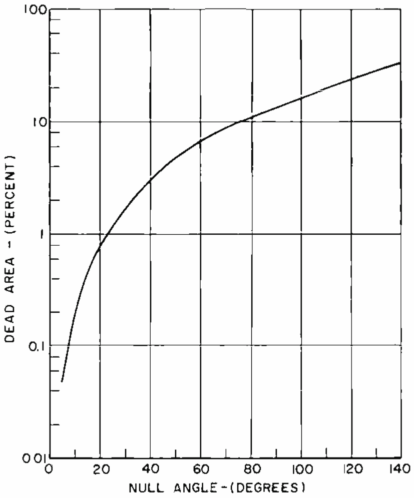
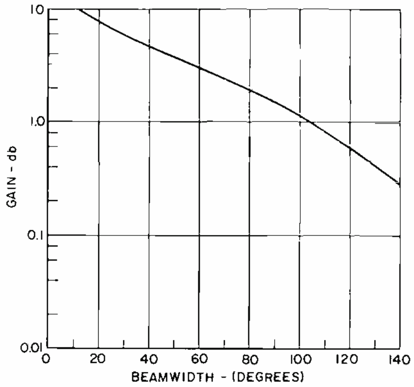


Fig. 2—Gain versus beamwidth for an omnidirectional antenna.



Because the satellite changes its position and angular orientation with respect to the ground station continuously, the polarization match between the two are important considerations. In addition, at some frequencies, the Faraday effect will cause polarization rotation during passage of the electromagnetic wave through the ionosphere. When the space antenna is randomly oriented to the ground antenna, studies[1] show that one terminal should have linear and the other circular polarization for high probabilities of communication. In general, orientation will not be random, but may involve the entire sphere and most likely will not be known at the ground station.

A type of diversity has been used to maintain continuous telemetry communication under these kind of conditions; elliptical polarization is used on the spacecraft so that no null occurs in its power pattern. On the ground, either dual-orthogonal linear antennas or both-sense circularly polarized antennas are used. Generally, the stronger of the two outputs is selected, but in some cases the signals are added in a simple fashion. This has worked reasonably well for the conditions of the transmitter on the satellite and receiving stations on the earth. However, the reverse path is somewhat less useful, since too much complexity is required on the spacecraft.

A variation of this scheme could be useful for the reverse-path situation. Briefly, this data would be telemetered to the ground terminal to indicate that the proper polarization transmission from the ground was being used. Thus, the ground transmitter could switch its polarization upon information from the spacecraft that the channel was not complete.

### TYPES OF RADIATORS

Types of radiators found useful in devising satellite antenna systems are: simple whips, slots, flat and conical turnstiles, planar and conical equiangular spirals, and helical. Patterns of whips and slots on both cylinders and ground planes have been investigated theoretically and experimentally, and pattern shapes to be expected for an installation can be estimated. But, vehicle dimensions are often of the same order as the wavelength, requiring further experimental development. This will likely always be more desirable than attempt-

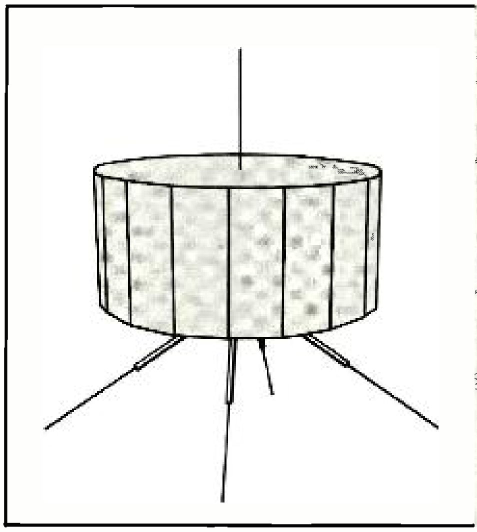


Fig. 3—TIROS satellite.

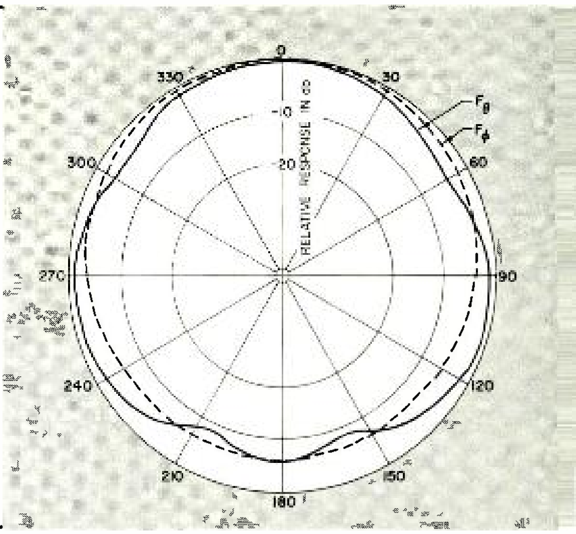


Fig. 4—Patterns of the TIROS turnstile antennas.

ing to compute the patterns. The shape of vehicles is not simple and protuberances and surface material effects play their part in modifying the pattern. Building a scaled model of the vehicle and conducting a measurement program at conveniently higher frequency is an excellent procedure for obtaining the basic pattern configuration desired. This can be done either on an outside range or in an anechoic chamber. Final impedance measurements and check patterns must be made at full scale.

The turnstile antenna has found wide use as a satellite antenna. Simplicity and pattern coverage account for this popularity. Basically, the turnstile consists of two electric dipoles crossed at right angles and fed in phase quadrature. The pattern is right-hand circular at one pole, left-hand circular at the other pole, linear at the equator (in the plane of the crossed elements), and elliptical at other angles. The over-all power pattern is within 3 db of being fully isotropic. Two modifications are worth noting: in one, the four quarter-wave elements are situated radially about a cylinder; in the other, they are located as elements of a truncated cone. In the first, if the cylinder is not large the pattern is not greatly affected. In the second, the pattern becomes a more nearly isotropic power pattern and the equatorial-plane linear polarization is rotated with respect to the plane.

The equiangular or logarithmic spiral antenna has features which recommend it for satellite use. It is inherently broadband, has circularly-polarized radiation, and a naturally broad pattern. In one configuration,[3] a one-sense nearly uniform circular polarization is achieved over a full hemisphere. An antenna[4] with an omnidirectional circularly polarized pattern is one widely used at air terminals for communication with aircraft: four angled-dipoles are fed in-phase and located around a one-third-wavelength-diameter circle. The beamwidth normal to the omnidirectional pattern is similar to that of a dipole.

### ENVIRONMENT

While space communication is no problem once orbit or an altitude above the atmosphere has been reached, quite the opposite is true on the launch pad and during the launch phase. The satellite or space vehicle will be surrounded by a fairing or shroud and fastened to the final-stage rocket motor. To be free of the extreme air buffeting and heating during travel through the atmosphere, antennas are usually contained within the fairing. Should this enclosed volume be inadequate, extendible or unfurlable techniques will be necessary. Budgeting of space and weight as well as the limits of feasible locations, makes combination antennas desirable. Antennas for widely different frequencies can be combined by locating the high-frequency configuration on a mast which itself radiates at the lower frequency. The use of different feeding or radiating modes is a convenient method of isolation. Broadband or frequency-independent-type antennas can be used with filters or diplexers to combine several communication functions into one antenna.

When the space vehicle is large with respect to wavelength and wide-angular coverage is necessary, the designer has two methods of attack. The antenna can be located far from the main body of the vehicle so that the angle subtended by the vehicle body is reduced to minimize effects on the pattern. When the vehicle is located along a natural null axis of the antenna pattern, even less effect is noticed; when such a location is feasible, a number of antennas can be located strategically about the vehicle body so that the sum of their patterns affords full coverage. Unless these various sources are operated in multiple channels, separated either in time or frequency, there will be angles of overlap in which interference patterns with consequent nulls exist. These antennas can be switched in singly by automatic command from a program control, by vehicle command with knowledge of orientation, or by command from a ground station. When individual antennas are widely spaced in wavelength, the nulls will be narrow and tolerable for some applications.

Although environment is a very important factor to consider in all antenna design, it is doubly so for spaceborne antennas. Antennas must be capable of operating in the final environment, space; but must also withstand launch conditions and may be required to operate throughout this severe phase. Furthermore, there can be no maintenance or replacement schedule to ease the requirements.

In the launch phase, shock and vibration accelerations are very high and cover a broad frequency spectrum. When the unit must operate through the launch period, power breakdown must be considered. In ascending in the atmosphere the antenna passes through a minimum breakdown pressure which establishes the design criteria. Unless precautions are taken, thermal heating as a result of air friction may be a problem; generally, the interior of the fairing will be cooled. All objects extending beyond the fairing will be subject to the full gamut of aerodynamic buffeting and heating. As the fairing is discarded when the region of small air drag is reached, care must be taken that antennas are not fouled in this process.

In the space environment with its small particle density, power breakdown becomes less of a problem unless the vehicle itself throws off material, either by design or incidentally. Such material may create surrounding ionization, requiring further consideration of power breakdown, propagation attenuation, and impedance match.

Malfunctions of equipment during and following launches have caused costly misfirings and caused many launches to be only partially successful. As a result, reliability of components and systems is stressed. Redundancy is built in with duplicate systems and subsystems. Related to antennas this may require, preferably, dual feeds completely decoupled rather than fail-safe switches. Reliability in antennas in gen-

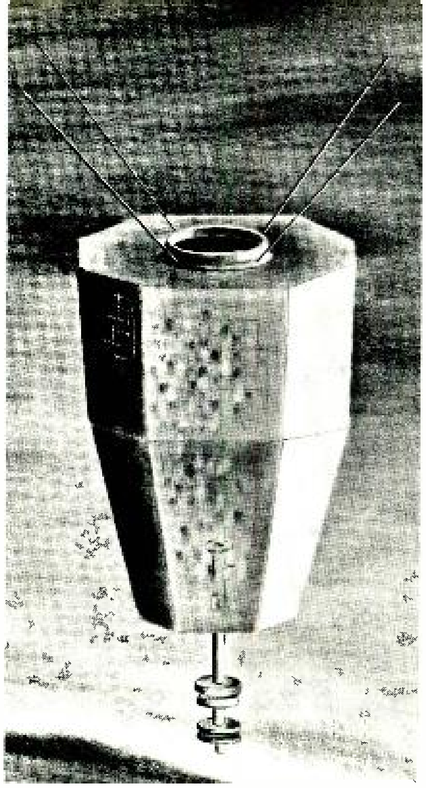


Fig. 5—Project RELAY satellite.

eral decries switches, active elements, extendible or retractable radiators, or moving parts. Materials used for fabrication need to be completely stable under the thermal and pressure variations and the particle radiation of space. The mechanical design must be closely related to operating conditions so that weight can be minimized without impairing the reliability of performance.

### TIROS

The TIROS weather satellite, sponsored by NASA and developed by the DEP Astro-Electronics Division, Princeton, has five versions which have been successfully launched and operated for long period of time. The antenna system consists of the five whip-type radiators shown in Fig. 3; two receivers in *command-receive* and five transmitters for transmitting beacon signals and telemetry data (and for weather pictures in video form) are accommodated. A single quarter-wave whip centrally located at one end serves for receiving at 140 Mc. Four whips fed as a turnstile are located at the opposite end of the satellite. Two telemetry transmitters at 108 Mc and two video-data transmitters at 235 Mc feed the two decoupled radiating modes of the antenna. Frequency separation in the multiplexing network is done with sections of transmission line. The whips use a quarter-wave sleeve to assist in the two-frequency matching scheme; patterns of this turnstile are shown in Fig. 4. The two linear components used in the diversity system of the ground station were measured; the full-sphere coverage of this system is evident.

### RELAY

The RELAY broadband-relaying satellite is likewise NASA-sponsored and RCA developed. The spacecraft, with antennas, is shown in Fig. 5. The four whips at the base are dual function and are fed in-phase quadrature by two telemetry transmitters at 235 Mc to radiate the two decoupled turnstile modes. Simultaneously the whips operate in-phase at 148 Mc in a dipole radiating mode for the command-receive function. The order of 25 db isolation between the function is achieved. The two types of patterns are shown in Figs. 6a and 6b.

The wideband relay antennas are located at the opposite end of the spin-stabilized spacecraft. The receive antenna at 2000 Mc and the transmit antenna at 4000 Mc are mounted on a common mast which also acts as a transmission line. Two radiation-mode-decoupled transmitters feed the radiating slots and two paralleled receivers are fed from the receiver slots. The radiation is omnidirectional about the spin axis and circularly polarized. A typical pattern through the spin axis is shown in Fig. 7.

**W. C. WILKINSON** graduated from Purdue University in 1941, with a BSEE. Since then, he has been employed by RCA; in 1941-1942, at the Manufacturing Co., Camden, N. J.; in 1942-1961 at the RCA Laboratories, Princeton, N. J.; and since March 1961 at the DEP Missile and Surface Radar Division, Moorestown, N. J. His experience has been in applied research and advanced systems development, RF transmission and components, and in antennas. Particular areas of experience are: narrow-beam rapid-scanning antennas at microwave and millimeter waves; airborne high-resolution radar; and ground-space communication. At present, he is a group leader in the Antenna Skill Center, engaged in developmental programs on satellite antenna systems. Mr. Wilkinson is a member of Sigma Ki, Eta Kappa Nu, and a Senior Member of the IRE.

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Fig. 6a, b—Two types of patterns for the dipole whip antennas of the RELAY satellite.

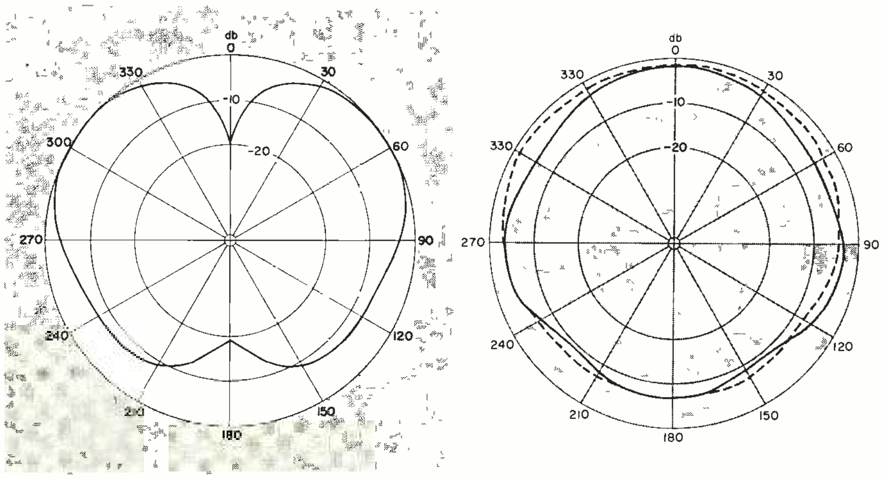
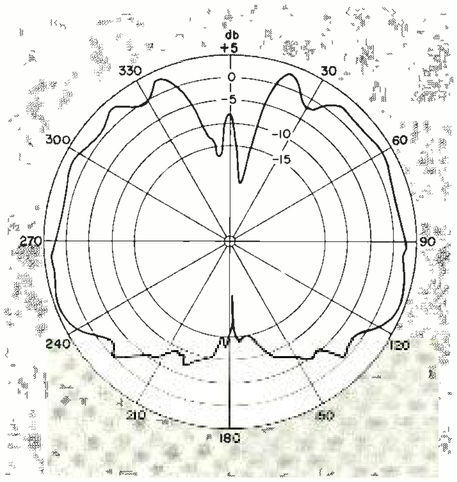


Fig. 7—A typical circularly-polarized pattern through the spin axis.



# ELECTRONICALLY STEERED RADAR-ANTENNA ARRAYS

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Modern search radars deal with problems of long ranges, target complexity, and extreme target speeds, while gathering detailed data in a very short time period. With electronic scanning, a target in a field of view that is large compared to a beamwidth may be engaged without moving the major bulk of the antenna. A radar-antenna array thus "electronically steered" can change a beam position in microseconds, provide simultaneous beams for increased data rate, and at the same time perform other functions such as surveillance, closed-loop tracking, and transmission of guidance information.

Prior to World War II, antenna design effort was largely concerned with arrays; such arrays included varying numbers of element-type antennas operated in unison to provide increased gain and directivity. During World War II, the range of practical, usable frequencies increased to 10,000 Mc and above. At these frequencies optical analogs became more attractive, and rapid strides were made in the fields of reflector-feed and lens-feed antennas; such antennas are analogs of optical diffraction-limited telescopes. The basic "telescope" concepts established during this period led to the design and construction of modern reflector and lens antennas—unchallenged in their applicability to most search radar systems.

However, it was recognized that certain search radar systems might require high transmitter power, high rates of change in beam-pointing angle, and unusual versatility in changing antenna characteristics to meet the requirements of a rapidly changing tactical situation. The advent of these advanced requirements was foreseen during the V-2 rocket raids of World War II; thus, extensive antenna system research ensued.

During recent years, such radar design effort has had to consider the launching of numerous satellites and possible mass ICBM attack. Because of the tremendous speeds of these rocket vehicles, their long range, and their potentially overwhelming multiplicity, radar system designers must obtain detailed data on many "uncooperative" targets in an extremely short time.

In a surveillance or search operation, targets are likely to be distributed in some unknown fashion throughout a solid angle of coverage which is large compared to the solid angle covered by the beam. Thus, the normal reflector antenna must be scanned at a fast enough rate to assure that a target will not slip through undetected. Long-range applications requiring high-gain antenna systems usually employ several beams operating simultaneously; thus, complete coverage can be completed in the short time dictated by the high target speeds. Moreover, when target position must be determined very accurately, a beam designed especially for this purpose may be added. In principle, one could add more and more dish-feed antennas to the system to satisfy particular purposes; but this solution soon becomes unwieldy.

### ELECTRONIC SCANNING

Various methods of electronic scanning have now become more attractive for high-speed, high-accuracy search radar antenna applications. The term *electronic scanning* denotes a large class of antennas with a common characteristic: that any target within a certain field of view (large compared to a beamwidth) may be engaged by the antenna without moving the major bulk of the antenna.

Fig. 1 illustrates the general configuration of electronically steered antenna-array systems of recent interest to the Antenna Skill Center of the DEP Missile and Surface Radar Division, Moorestown. Shown are some of the array elements, which in actual practice may number in the hundreds or even thousands, arranged in a two-dimensional planar array. Such large systems are characterized by very high radiated power. The total radiated power corresponds to the power sum of all transmitter modules concentrated into a beam defined by the aperture dimensions.

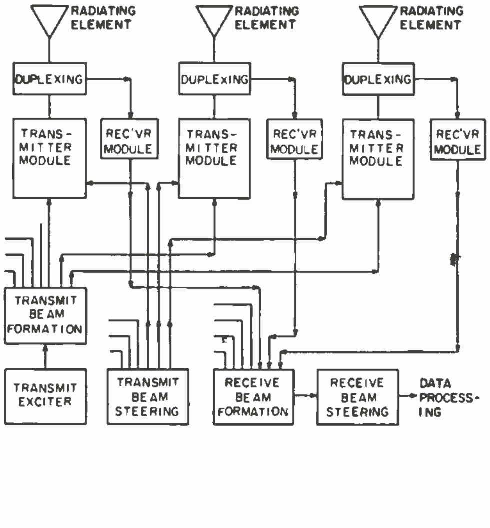
Receiver modules are generally considered to be relatively low-noise, often solid-state amplifiers with sufficient gain to overcome losses to signals that occur in steering and beam-forming networks. The receiving beamwidth is determined primarily by aperture dimensions of the array and the location of those antenna elements having active receiver modules. Beam-steering networks shown refer to any of several techniques used to generate relative phase or delay control to the elements performing the transmitting or receiving functions. The beam-formation networks refer to those used for summing (in several different ways) the individual outputs of the receiver modules, and/or dividing the transmitter-exciter signals feeding the transmitter modules.

Electronically controlled systems of this general type are capable of changing beam position in space within microseconds, providing simultaneous beams for increased data rate, and simultaneously carrying out such functions as surveillance, closed-loop tracking, and the transmission of guidance information. Furthermore, with surveillance programs designed to fit specific threats, the increased agility and flexibility can result in a significant saving of several db in the over-all transmitter power requirements compared with that of a mechanically steered reflector system.

### STEERABLE ARRAY CHARACTERISTICS

Although dish-feed antennas and electronically steerable arrays have a large area of overlap in functional capabilities, there are distinct differences that strongly influence the design of the entire radar system with which the antenna is to be used. This is true in spite of the fact that both types of antennas have the same major conceptual characteristics of resolving power (beamwidth), antenna gain, and ambiguous (sidelobe) response. The major contrasts arise from the differences in the basic geometry of beam formation and the comparatively high degree of freedom present in the design of an array aperture. Since similarities between the two antenna types

Fig. 1—General configuration of an electronically steered array.



are accepted rather naturally, the ensuing discussion dwells on the differences of the two antenna types.

The major characteristic of the dish-feed antenna is that electrical properties of the radiating structure remain constant, except for small perturbations which may be intentional or unintentional. For this reason, the plot of gain-versus-angle, or the *pattern*, is a constant when the angle-measurement coordinates are fixed to the radiating structure of the antenna. The pattern shape may be perturbed intentionally by moving the feed (as in a mechanical conical scanner), or unintentionally by allowing changes in the radiating structure and its surroundings (e.g., dish distortion, feed movement, or presence of the ground). These characteristics allow one to consider the beam as invariant in shape and specified in spatial position by two angles—the same angles which determine the angular position of the mechanical structure.

In contrast, electronically steerable arrays give rise to an entirely different method of specifying beam shape and position. The Fraunhoffer, or *far-field*, pattern of an electronically-steerable array is (by definition) not a fixed spatial function with respect to the radiating structure; and unlike the reflector-feed antenna, its pattern is variant in shape with respect to spatial coordinates. The pattern is, however, relatively invariant in another coordinate system, the so-called *phase-coordinate system.* For this reason, the angle-data-handling circuits of an antenna system of this type generally work in terms of phase gradients, rather than actual spatial angles.

Since the far-field pattern of an electronically-steered array is not a fixed function with respect to the radiating structure, the properties are more readily analyzed in a phase-coordinate system. The phase-coordinate system was originally described by Spencer and Austin[1] and more recently by Von Aulock[2] for the two-dimensional case.

Using the geometry shown in Fig. 2, and assuming the transmitting current in the *m*th row and *n*th column is:

$$I_{mn} = |I_{mn}| \exp[-2\pi j(n\Delta\phi_\alpha + m\Delta\phi_\beta)]\exp[-j\omega t] \tag{1}$$

Then, the far-field pattern is:

$$|A(\psi_\alpha,\psi_\beta)| = \left| \sum_{m=1}^{M} \sum_{n=1}^{N} |I_{mn}| \exp[2\pi j(n\psi_\alpha + m\psi_\beta)] \right| \tag{2}$$

**R. M. SCUDDER** graduated from Purdue University in 1943 with the BSEE and joined RCA at that time. After two years as a design engineer, he joined M&SR to work on antenna and microwave component development. A few of the projects with which he has been directly associated as Microwave antenna design engineer or supervisor are: AN/SPS-12 shipboard search equipment; AN/UPS-1 lightweight search radar; AN/UPS-1 full-coverage antenna project; Bumblebee and Terrier monopulse tracking radars for active air defense systems; AN/FPS-16 instrumentation radar; Talos tracking and guidance radars; and BMEWS Tracking Radar. Recently, he has been concerned with advanced study and development of high resolution electronically-steered arrays. He holds two patents relating to microwave antennas, has served on an IRE sub-committee on TR tube standardization, and was chairman of an EIA sub-committee on new wave-guide standards.

**C. P. CLASEN** received his AB in Physics from Washington University. After two years of military service, he joined the RCA Graduate Study Program in 1957, (He received the MS in Physics in 1959). Mr. Clasen performed applied research in the areas of broadband low-noise TWT receivers and was associated with the development of the AN/FPS-16 instrumentation radar. Since 1957, Mr. Clasen has been associated with RCA's applied research program in the field of electronic scanning, with responsibility for the Madre antenna concept. His chief areas of investigation are: electronically steerable antenna systems, beam pointing uncertainty, Huggins phase shifters, monopulse frequency scanning, and the peak power capabilities of the radial waveguide scanning antenna. He is senior scientist of the electronically steerable antenna Applied Resarch program at the Moorestown Antenna Skill Center.

Where: $\psi_\alpha = (d/\lambda)\cos\alpha - \Delta\Phi_\alpha$ turns;
and
$\psi_\beta = (d/\lambda)\cos\beta - \Delta\Phi_\beta$ turns. (3)

One turn $= 2\pi$ radians. The above equations hold for a rectangular array having $M$ rows and $N$ columns of elements spaced by distance $d$. The current in the elements vary in time as $\exp - j\omega t$ and are referenced in phase to the common *drive* point. The equation also holds for *receive* if the $\Delta\phi$ is always considered to be a phase advance. In the receive case, Equation 1 represents the current contributed to the summing circuit by a unity current in element *mn*.

The field pattern in phase coordinates, then, is only a function of $\psi_\alpha$, $\psi_\beta$, and the choice of $|I_{mn}|$, the current excitation of the various elements; $A(\psi_\alpha, \psi_\beta)$ is maximum at $\psi_\alpha = \psi_\beta = 0$, which corresponds to the peak of the main lobe. Maxima also appear when $\psi_\alpha$ and $\psi_\beta$ are integers giving rise to "grating lobes".

The steering required to bring the nose of the beam to $\alpha_0$, $\beta_0$ is:

$$\Delta\Phi_\alpha = \frac{d}{\lambda}\cos\alpha_0 \text{ turns}$$

$$\Delta\Phi_\beta = \frac{d}{\lambda}\cos\beta_0 \text{ turns} \tag{4}$$

Equations 4 relate phase coordinates and the natural data-handling of the system to geometrical coordinates.

Substituting Equations 3 and 4 into Equation 2 yields the expression of the array pattern in spatial coordinates:

$$A(\alpha,\beta) = \left| \sum_{m=1}^{M} \sum_{n=1}^{N} |I_{mn}| \exp\{2\pi j | n(\cos\alpha - \cos\alpha_0) + m(\cos\beta - \cos\beta_0) |\} \right| \tag{5}$$

Fig. 2—Planar array geometry.

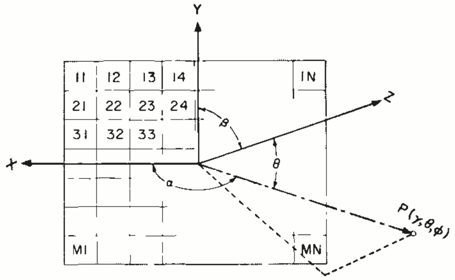
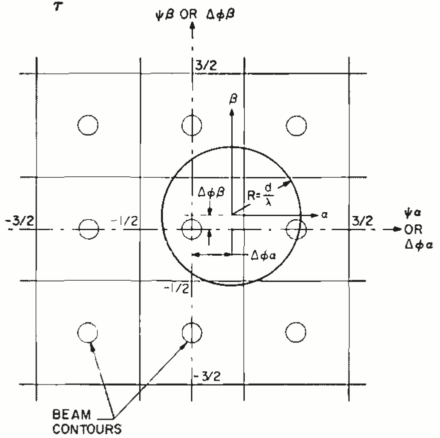


Fig. 3—Relationship of A ($\psi\alpha$, $\psi\beta$) and the "visible region" represented by the circle (radius, $\frac{d}{\tau}$).



The meaning of the phase-coordinate system can be illustrated by considering a three-dimensional figure. Assume that the axes in the horizontal plane of that figure are $\psi_\alpha$ and $\psi_\beta$, and the values of $A(\psi_\alpha, \psi_\beta)$ are plotted on the vertical axis. The result is a three-dimensional representation of the array voltage sensitivity. If this is represented in two dimensions by a contour map in the $\psi_\alpha$, $\psi_\beta$ plane, the result is similar to that shown in Fig. 3. The small circles represent a given contour on the main beam at the center, and on the grating lobes centered at integral values of $\psi_\alpha$ and $\psi_\beta$.

Steering the array corresponds to moving the pattern $A(\psi_\alpha, \psi_\beta)$ beneath the "visible region" represented by the circle of radius $d/\lambda$ in Fig. 3. The appearance of a grating lobe forward of the array occurs when the contour map is moved (steered) so far that one of the grating-lobe maxima at integral values of $\psi_\alpha$ and $\psi_\beta$ appears within the "visible region." Normally, for radar use the element spacing is related to the desired maximum steering angle so that grating lobes do not appear; otherwise, ambiguous target returns could result. Array gain and impedances are also affected adversely when grating lobes appear. (Many forms of interferometers, however, use a large visible region, making use of the multiple ambiguous lobe structure.) In the typical electronically-steered array, $\alpha$ and $\beta$ are limited to ±45°, and $d/\lambda$ is set between 0.5 and 0.6 to preclude the possibility of grating lobes deteriorating the array's performance. Under these conditions, the maximum value of $\Delta\Phi$ would be between 0.35 and 0.43. The suppression of grating lobes at the highest operating frequency usually determines the radiating-element grid spacing.

### SPACE-TAPERED ARRAYS

Thus far, it has been implied that an active radiating element is placed at each grid point on the array with the spacings as indicated above. Such is not necessarily so for large arrays, particularly receiving arrays. In most cases, a transmitting array is made as efficient as possible through the use of equal excitation of a completely filled array matrix. However, to achieve acceptable round-trip sidelobes economically, the associated receiving array is normally *space tapered* to approximate smooth illumination functions. In space tapering, active receiver modules are omitted in a random manner so that, as an integrated effect, a virtually smooth amplitude illumination taper is provided. The Antenna Skill Center has developed a procedure to determine the design of such large space-tapered arrays where, for example, 30-db sidelobes are obtained with 40 percent of the elements driven where suitable tolerances are held in the equipment. This typical design represents the maximum-gain case for sidelobes of this magnitude. A smaller portion of driven elements could be used with a proportionally-decreased antenna gain, with sidelobe performance degraded only slightly.

### BEAM STEERING AND FORMING

As indicated in Equations 4, beam steering is accomplished by relative phasing of the radiating elements, creating equiphase fronts which are normal to the beam angle. As a beam is steered from broadside, in the $\alpha$ plane, the total relative phase shift between the end elements is $(N-1)\Delta\Phi\alpha$. When the beam is moved in angle by one beamwidth (for a uniformly driven array), the relative phase shift of the end elements changes by $(N-1)/N$ turns, or about 360° in a large array. All other radiating elements placed between the end elements are phased proportionally less than 360°. For the normal angles of coverage required, the total relative phase shift across the array is large (40 or 50 turns in typical cases).

### BEAM-STEERING EQUIPMENT

The equipment necessary to electronically generate the beam-steering phase tapers may take many forms. Figs. 4 and 5 show two typical techniques. The heterodyne scheme of Fig. 4 is normally operated at an intermediate frequency and provides low-level exciter signals to the transmitter modules and/or second-local-oscillator signals to the receiver modules. The phase taper derived is a function of the steering frequency $F_s$, applied to the tapped RF delay line (the electrical phase length of the delay is essentially linear with applied frequency). The desired frequency $(F_t)$ to be used by the transmitter and/or receiver modules is recovered by mixing (heterodyning) at each output terminal.

Two-dimensional steering is accomplished by using two such systems where the individual outputs are combined in a second-stage mixing process. This heterodyne phase technique is basically the same as that used in the experimental model *radial waveguide scanning array* developed by RCA.[3] A limitation of this approach is that the steering or beam-slewing rates available are determined primarily by the transit response of the delay line networks; thus, in the typical case for large arrays, a settling time of several microseconds may be involved.

Another class of phasing techniques, a passive network, is shown in Fig. 5. Here, beam formation (summing of the contributions from the elements) and steering are combined in a parallel network consisting of hybrid junctions and fixed phase-shift elements. Beam steering is actually a case of selecting fixed overlapping beams (separated by constant intervals of $\psi$); this is done by switching to one or more of the terminals at the bottom of the network. Simultaneous beam operation using a single network is a feature of this approach. Such a network can be used at an intermedi-

Fig. 4—Functional diagram of heterodyne phasing network used for beam steering.

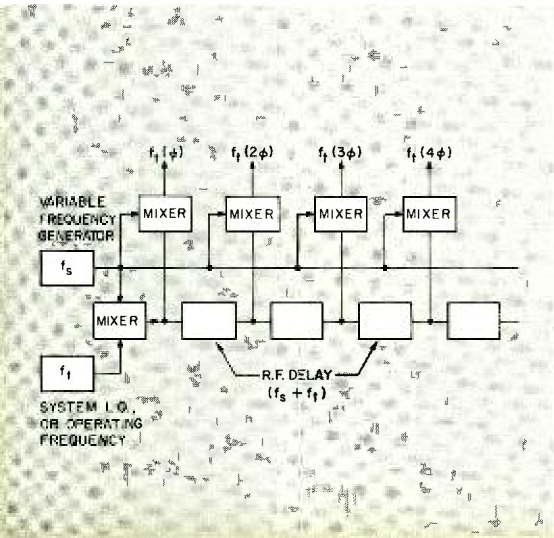


Fig. 5—Functional diagram of a parallel-coupler beam-steering matrix.

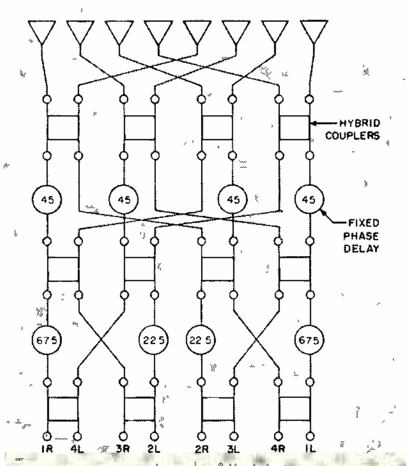
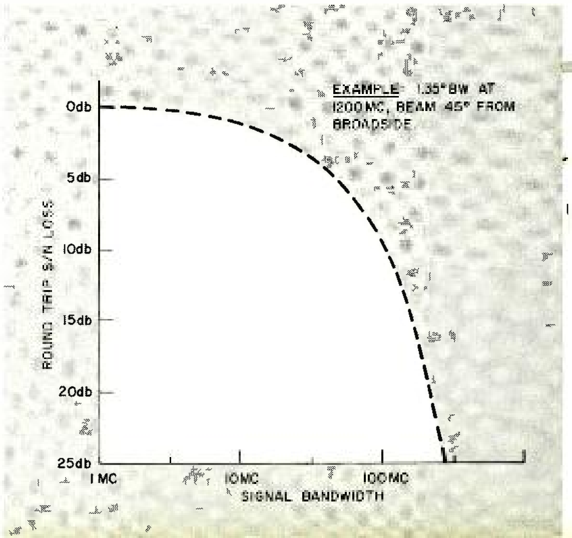


Fig. 6—Effect of SiN Loss on a phased array versus the signal bandwidth.



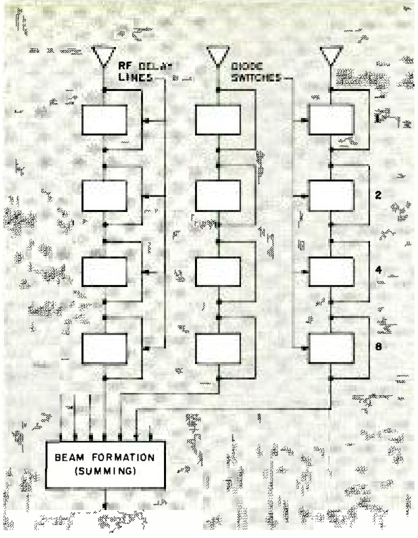


**Fig. 7—A variable time-delay steering arrangement (binary increments).**

ate frequency or at the system transmitted RF.

### ARRAY MUTUAL-COUPLING EFFECTS

Because the steering of arrays involves altering the relative phase of signals driving the elements, the mutual coupling properties between radiating elements of the array becomes a major consideration. Array gain, element patterns, and the element driving-point impedances, are all interrelated functions of steering angle. This inter-relationship is the subject of much analytical and experimental industry effort; the objective is to realize full aperture gain (modified by cos $\theta$ where $\theta$ is the scan angle off broadside) and minimum change in element impedance with scan-angle changes. The goal is to reduce cost by eliminating auxiliary equipment ordinarily required to compensate for impedance changes, reflection and resistive losses, and unwanted spurious lobes on the radiated pattern. Antenna Skill Center studies[4] indicate that when patterns of the individual radiating elements (the pattern obtained when a single element is driven while all its neighbors are terminated) are of the form cos $\theta$, optimum array gain-impedance properties are provided.

### SKILL CENTER ARRAY PROGRAM

Current trends in system requirements indicate the need for electronically-steered radar systems to provide very high range-resolution capabilities along with the other properties inherent in their use.

Increased range resolution, however, implies increased signal bandwidth, other properties remaining equal. For example, to resolve in range to an accuracy of 2.5 feet requires equivalent pulse lengths of the order of 5 nsec, implying signal bandwidths of 200 Mc. Increase in the operating bandwidth may also stem from the need to perform multiple functions such as tracking, surveillance, and command at different frequencies.

Referring to Equation (4), note that for a given *phase taper*, the angular position of a beam is a function of the operating wave length. For wide instantaneous-signal bandwidths, the beams tend to *smear*, with resulting loss in signal-to-noise ratio, since different frequencies in the signal band are concentrated at different steering angles. This effect increases with an increasing beam displacement from broadside. Fig. 6 illustrates the signal-to-noise degradation as a function of signal bandwidth for a typical array size with the beam steered 45° from broadside. In effect, when the array is properly steered it acts as a bandpass filter, attenuating the side-frequency components of the signal spectrum; such results are characteristic of the Fig. 4 and Fig. 5 steering networks.

Derivation of array- and beam-steering techniques (basically frequency independent) is the subject of the electronically-steerable array development being carried out by the Antenna Skill Center. Basic objectives of this development apply to an array system having the following characteristics: a 250-Mc signal bandwidth at L-band (corresponding to a 2-foot range-resolution capability), polarization diversity, and beam-slew times of less than a microsecond.

To overcome the loss in signal-to-noise performance and smearing which would be present in pure phased systems operating at these bandwidths, it is necessary to steer the array by a variable time delay; to do this, the length of the RF path from the target through the element array to the summing point must be equalized for each beam position. In this case, the phase shift of any spectral component is also inversely proportional to wave length and Equation 4 is independent of frequency. Thus, under transmit or receive conditions, the beam remains stationary in space as a function of frequency and the smear experienced in purely phased systems does not exist.

Although phase steering can be accomplished at some intermediate frequency within the antenna system, time-delay steering must be done at the basic operating RF, or equivalent. The approach under development (Fig. 7) is one employing switched RF delay lines controlled by RF diode switches. Performance is primarily dependent on the diode switch, and the feasibility depends upon the cost of such switches in large quantities. Fig. 8 shows a development model of an L-band switch and delay element having 0.7-db loss (closed) with 30-db isolation; an inexpensive Type 24 computer diode is used as the basic control element. The diode switch and the RF delay increments employ printed or strip RF circuit configurations.

An 81-element crossed-dipole array has been constructed (Fig. 9) for the purpose of optimizing the array gain and the mutual coupling effects over a wide signal bandwidth. Data taken on the crossed-dipole array will also serve to support analytical conclusions indicating that element impedances can be maintained nearly constant with beam steering by shaping of the element pattern. The dipole array and the switched delay-steering network will be integrated at a later date to form an operating system for evaluation tests.

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4. C. P. Clasen, *unpublished report.*

**Fig. 8—Developmental model of an L-band switch and delay element.**

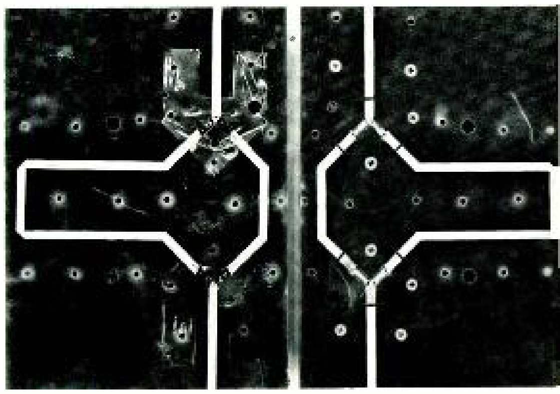
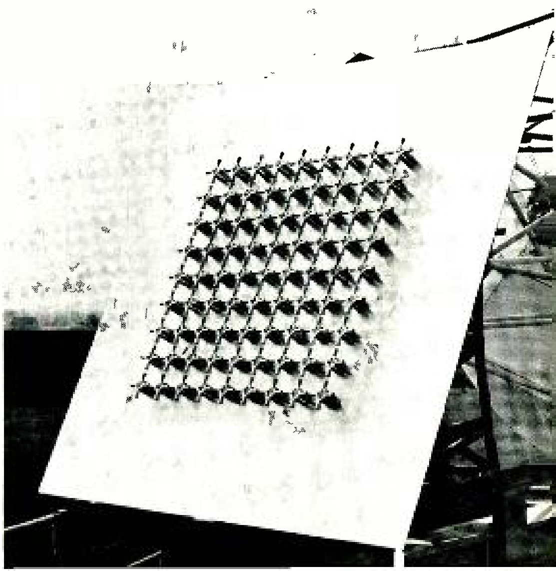


**Fig. 9—Photo of an 81-element crossed-dipole array.**



# LOW-NOISE RADAR ANTENNA SYSTEMS

This paper emphasizes dependence of radar range on the total system noise and gives a method of evaluating the contribution of each noise source to the total system noise. In particular, antenna noise, transmission-line noise, and receiver noise are expressed in common terms and combined to obtain a total system sensitivity expression. This expression is then used to assess the importance of each noise contributor and relate performance and future trends in low-noise radar systems.

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Evolution of space travel and intercontinental ballistic missiles has created an urgent need for radar systems with ever increasing target-detection ranges. The three primary methods of expanding radar detection range are: 1) increasing effective area of the antenna, 2) increasing transmitter power, and 3) improving over-all sensitivity of the receiving systems.

The first two approaches have been exploited until further improvement appears essentially uneconomical. Moreover, recent developments in ultra-low-noise receivers, such as masers and parametric amplifiers, have opened the door to tremendous improvements in radar sensitivity at reasonable cost.

Thus, the progress made in these areas of increasing the radar detection range has stimulated the investigation of other noise sources: atmospheric noise, radio-star noise, and transmission line losses. Extensive effort has been expended to develop *low-noise antenna systems* with low-loss radar transmission line components, as well as low-noise receivers.

## TYPICAL RADAR SYSTEM

In the typical radar system of Fig. 1, the radar transmits a high-power pulse of microwave energy and attempts to detect any portion of that pulse reflected by the target. The magnitude of this reflected signal $S_A$ can be stated in terms of radar constants and the distance to the target. This incoming return signal is given by

$$S_A = \frac{PA^2\sigma}{4\pi\lambda^2R^4} \qquad (1)$$

Where: $S_A$ = signal power level in watts, $P$ = peak transmitted power of the radar in watts, $A$ = effective area of the antenna in square meters, $\sigma$ = effective cross sectional area of the target in square meters (dependent on shape and size of the target), $R$ = linear distance between the antenna and the target in meters, and $\lambda$ = wavelength of the transmitted microwave signal in meters.

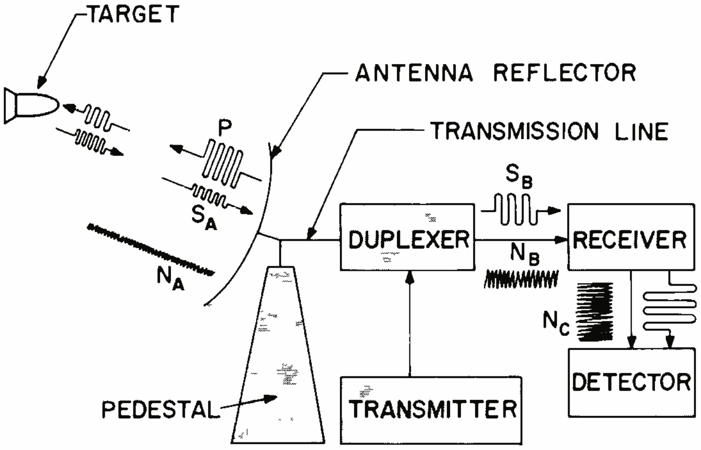


Fig. 1—A typical radar system, showing the signal paths.

Unfortunately, this reflected signal pulse arrives at the antenna along with unwanted noise power denoted as $N_A$ in Fig. 1. As the receiver amplifies the desired signal (and unwanted noise) it also adds internally generated noise. As the target moves away from the system, the signal $S_A$ becomes weaker and weaker. The noise $N_A$, however remains constant. Eventually a threshold is reached, beyond which the signal cannot be differentiated from the noise. If we denote this threshold level (the minimum value of return signal that the system can detect) as $S_{min}$, we can solve Equation 1 for the maximum radar range

$$R_{max} = \left(\frac{PA^2\sigma}{4\pi\lambda^2S_{min}}\right)^{1/4} \qquad (2)$$

It is seen then, that the maximum range of the system is dependent on the effective aperture area of the antenna, the peak transmitter power and the noise level of the system through $S_{min}$. A description follows of the contributors to the noise level, the relative importance of each, and means of reducing their output.

## SOURCES OF NOISE

There are, in general, two noise sources of interest to this discussion; *shot noise* and *thermal noise*. Shot noise is produced by random electron motion in an electron stream such as that employed in a triode, TWT, or a tunnel diode. Shot noise sources are generally present only in amplification stages of the receiver and these noise contributions are included in a receiver figure of merit called *noise figure*. It will become clear later, when noise figure is defined, that detailed knowledge concerning noise sources in the receiver is not pertinent to the discussion. Thermal noise, however, is produced in other portions of the system such as in the antenna and transmission line, and a full understanding of this noise source is vital to the discussion of the radar stages. Generation of thermal noise is best analyzed from the classical black-body radiation standpoint.

When radiant energy at any frequency strikes a body, three processes take place: 1) some of the energy is transmitted through the body, 2) some is reflected from it, and 3) some is absorbed. The transmitted and reflected portions of the energy do not increase the temperature of the body. The absorbed energy portion causes increased molecular activity, resulting in a temperature in-

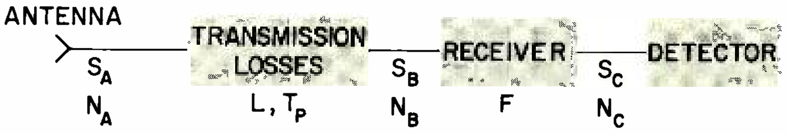


Fig. 2—Equivalent circuit of a radar showing where transmission losses occur.

crease of the body. If all the incident energy is absorbed, and none is transmitted or reflected, the body is called a *black body*, and its absorption coefficient $\propto$ is 1. Since the body must be in thermal equilibrium all of the absorbed energy will be emitted. Consequently, any body having absorptive properties in a given frequency range emits energy in that band; this emitted energy is a function of the physical temperature of the body and its absorption coefficient. The total noise power available from a radiating body is $\propto KT_pB$, where $\propto$ = absorption coefficient (1 for a black body), $K$ = Boltzmans constant, $B$ = frequency bandwidth, and $T_p$ = physical temperature of the body in °K. This emission of energy is the basic source of noise that limits radar performance. The absorptive body can be a simple resistor, lossy transmission circuits, or atmospheric absorbers. The energy emitted from these bodies is commonly referred to as *Johnson* or thermal noise.

### TRANSMISSION LOSSES

As shown in Figs. 1 and 2, transmission losses occur between the antenna and the first amplification stage of the receiver. The main transmission losses occur in the transmission line itself, rotary joints, duplexer, and couplers or monitoring devices added before the receiver.

The degradation in signal-to-noise ratio due to transmission losses can be related to insertion loss $L$ and the physical temperature $T_p$ at which losses occur. Consider the lossy transmission line shown in Fig. 3a. If the transmission line, of physical temperature $T_p$ extends to infinity on both sides of a reference plane, noise waves (of power level $KT_pB$) will travel both to the left and right of this reference plane. That is, an infinite and uniform transmission line at physical temperature $T_p$ generates an available black-body noise of $KT_pB$.

To examine the effect of a signal passing through the lossy line, consider the line to be intersected by two planes separated by a section whose total insertion loss is $L$ (Fig. 3b.): The noise entering this section of line at plane 1 is $KT_pB$. Some of this power must be absorbed ($P_{abs}$) by the lossy line:

$$P_{abs} = KT_pB - \frac{KT_pB}{L} \qquad (3)$$

However, the noise power produced at plane 2 is $KT_pB$; therefore, a noise power generated within the lossy section of the line is equal to $KT_pB - KT_pB/L$.

A signal passing through the lossy section of line is attenuated—and as we have shown, a certain amount of noise is added to the system. The signal power at plane 2 is

$$S_2 = \frac{S_1}{L} = S_{out} \qquad (4)$$

But, the noise power at plane 2 includes an added noise term:

$$N_2 = \frac{N_1}{L} + KT_pB\left[1 - \frac{1}{L}\right] = N_{out}$$

Hence:

$$\frac{S_2}{N_2} = \frac{S_{out}}{N_{out}} = \frac{\dfrac{S_{in}}{L}}{\dfrac{N_{in}}{L} + KT_pB\left(\dfrac{L-1}{L}\right)} \qquad (5)$$

$$\frac{S_{out}}{N_{out}} = \frac{S_{in}}{N_{in} + KT_pB(L-1)}$$

It can now be assumed that plane 1 is at the radar antenna; therefore, $N_{in}$ is the antenna noise $KT_AB$ and the signal-to-noise ratio at the receiver input is:

$$\frac{S_B}{N_B} = \frac{S_A}{KT_AB + KT_pB(L-1)} \qquad (6)$$

The degradation in signal-to-noise ratio due to transmission line losses in the system are seen to be dependent on the magnitude of the loss and the physical temperature of these losses. Degradation can be reduced by lowering transmission line losses and physical temperatures.

Much effort has been expended to design duplexers with extremely low insertion losses. Some transmission line components have even been cooled to extremely low temperatures in systems where cooled RF amplifiers are used, thereby reducing the $T_p$ term in the noise equation.

### RECEIVER NOISE PERFORMANCE

The degradation in signal-to-noise ratio due to the receiver can be evaluated in terms of *noise figure*, a figure of merit that is used to describe receiver noise properties. The average noise figure of a two-port transducer is defined[1] as the ratio of:

1) the total noise power delivered into the output termination by the transducer when the noise temperature of the input termination is maintained at a standard 290°K at all frequencies to,
2) that portion of (1) engendered by the input termination. For heterodyne systems, (2) includes only that portion of the noise from the input termination which appears in the output via the principal frequency transformation of the system, and does not include spurious contributors such as those from an image-frequency transformation.

This can be simply stated in equation form:

$$F_1 = \frac{\textit{total noise power delivered to the output}}{\textit{noise power output due to an input noise power of } kT_oB}$$

$$F_1 = \frac{KT_oBG_1 + N_1}{KT_oBG_1} \qquad (7)$$

Where: $F_1$ = noise figure, $T_o$ = 290°K, and $G_1$ = power gain of transducer.

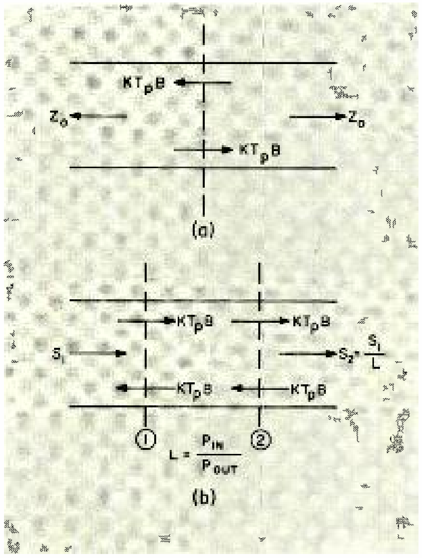
Solving for the noise due to the receiver alone:

$$N_1 = (F_1 - 1)KT_oBG_1 \qquad (8)$$

We now have all the information necessary for finding the final signal-to-noise ratio and the total noise output. The signal at $C$ is:

$$S_c = G_1 S_B = \frac{G_1 S_A}{L} \qquad (9)$$

Fig. 3—Representation of: (3a), a lossy line, and (3b), insertion loss (L).



The noise output at $C$ is the product of the noise at $B$ and the gain of the receiver plus the noise produced in the receiver $N_1$:

$$N_c = \left[\frac{KT_AB}{L} + KT_pB\left(\frac{L-1}{L}\right)\right]G_1 + (F_1-1)KT_oBG_1 \quad (10)$$

Therefore:

$$\frac{S_c}{N_c} = \frac{S_A}{\frac{KT_AB}{L} + \frac{KT_pB(L-1)}{L} + (F_1-1)KT_oBG_1} \quad (11)$$

$$\frac{S_c}{N_o} = \frac{\frac{S_AG_1}{L}}{KT_AB + KT_pB(L-1) + (F_1-1)LKT_oB}$$

**NOISE TEMPERATURE**

The amount of noise from the various contributors in the system is commonly expressed in terms of noise temperature in °K. There are two advantages of using the noise-temperature nomenclature: 1) consistent units can be used for comparing antenna noise with the noise generated in other components in a radar system, and 2) over-all radar sensitivity can be conveniently obtained with the antenna noise contribution included (a difficult task in terms of noise figure only). Equation 10 can be used to define the system noise temperature referenced to the input terminals of the antenna. $N_c$ is defined as:

$$N_c = KT_sB\frac{G_1}{L} \quad (12)$$

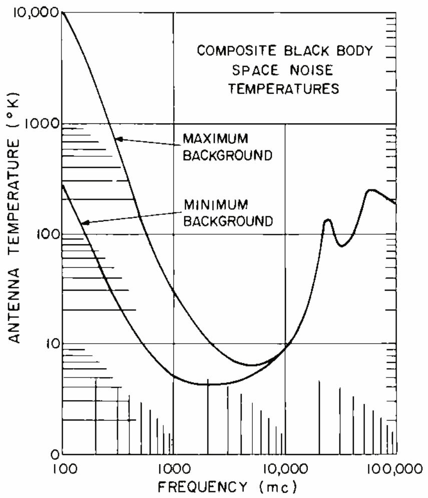


Fig. 4—Antenna temperature versus frequency for zenith observations.

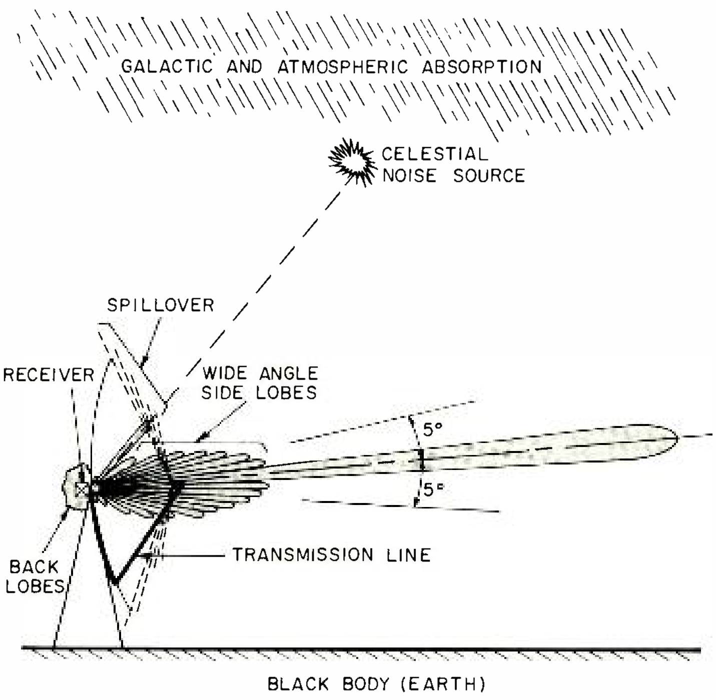


Fig. 5—Noise sources.

Equating equations 10 and 12, we find:

$$T_s = T_A + T_p(L-1) + LT_o(F_1-1) \quad (13)$$

In equation 13, $T_s$ represents the total radar system noise; $T_s$ is the physical temperature of a matched resistor which, when placed across the input terminals of a noise-free system with equal gain, would generate an amount of receiver output noise equal to that of the actual contributions from the antenna $T_A$, transmission losses $L$, and receiver noise figure $F_1$.

**ANTENNA NOISE TEMPERATURE**

The importance of antenna noise is emphasized by considering a perfect radar system which generates no internal noise of its own; here, antenna noise places the ultimate limitation on radar sensitivity. The effective antenna noise temperature can be defined as the temperature at which an equivalent resistor must be maintained to produce a noise power equal to that received by the antenna.

The noise received by an antenna is produced by black-body radiation from the various thermal noise emitters surrounding the antenna. The amount of noise available to the antenna, then, is the product of the absorption coefficient of these emitters and their ambient temperatures ($\alpha KT_pB$). This is the noise power available; however, the fraction of this noise power that is acceptable in the antenna is a function of the directional properties of the antenna. More power is received via the main beam of an antenna than from the side lobes. The noise received by the antenna from each direction in space is a function of the power emitted into the antenna from that particular direction and the ambient temperature of the emitting body. The antenna noise temperature can be obtained by slicing the antenna pattern into discrete sections or rays, and then determining the weighted average of noise contributions from all rays.

Physically, the noise generators are: the ground and sea absorption, the galactic noise of the sun, the stars, and other heavenly bodies, and the atmospheric absorption (likened to transmission line loss) due to the oxygen and water vapor in the atmosphere.

The general level of noise associated with galactic noise sources and atmospheric absorption has been studied in detail; the graph of Fig. 4 gives the minimum achievable antenna noise temperature at a given frequency.

At frequencies up to 1 Gc, galactic absorption and radiation are the dominant noise sources in the sky, and above 10 Gc the atmospheric absorption becomes the major noise source. Between 1 and 10 Gc, there exists a so-called *cosmic window* where ground absorption is the predominant noise contributor. It can be seen that the optimum frequency for low-noise operation is in the range of 1 to 10 Gc.

The directional characteristics (called patterns) of a reflector type radar antenna are such that approximately 80

**TABLE I—Effective Antenna Temperature**

| | Effective Temp. °K, $T_n$ | Weighting Factor $A_n$ | Weighted Temp. °K |
|---|---|---|---|
| 1. Atmosphere abs. | 5 | 0.8 | 4 |
| 2. Earth | 300 | 0.1 | 30 |
| 3. Galactic noise in side lobes | 20 | 0.1 | 2 |
| 4. Galactic noise in main beam | 20 | 0.8 | 16 |
| effective antenna temperature, $T_A = 52°K$ | | | |

percent of the total transmitted power is in the main lobe, 10 percent in the side lobes, and 10 percent in the back lobes (the entire rear hemisphere). Energy in the back lobes is composed of: 1) energy transmitted by the microwave feed which passes through the reflector if it is not solid, 2) the portion that does not strike the reflector (called *spillover*), and 3) the portion striking the reflector edge that generates currents on the rear surface of the reflector. Since antennas are reciprocal devices, i.e., their behavior on transmission is identical to that on reception, these same proportions will exist for the total received power (see noise contributions illustrated in Fig. 5).

The noise temperature seen by the antenna can be determined by summing up the noise contributions in each slice or ray of the antenna pattern—and applying the appropriate weighting factor.

Mathematically, antenna temperature is expressed by

$$T_A = \sum_{1}^{p} A_n T_n \qquad (14)$$

Where: $A_n$ is the fraction of the total power contained in the $n$th slice, and $T_n$ is the effective temperature of the absorbing media of the $n$th slice. The noise power of the antenna can then be expressed as $KT_AB$. The evaluation of antenna temperature is demonstrated in the example shown in Fig. 6. For this example we have chosen:

1) an antenna elevation angle of 90°
2) a noise level due to atmospheric absorption of 5°K
3) an average ground temperature of 300°K and a ground absorption coefficient of 1.0
4) an average galactic noise of 20°K
5) an antenna which transmits 80 percent of the energy in the main beam, 10 percent in the side lobes and 10 percent in the back lobes.

Referring to Fig. 6, calculated antenna temperature is shown in Table I. Hence the effective antenna temperature $T_A$ for this example is 52°K.

When 20 percent of the received antenna power is obtained from the back lobes, the noise contribution from item 2 Table I becomes 0.2 × 300°K = 60°K, producing an antenna temperature of 82°K. Consequently low back-lobe levels are important considerations in achieving low-noise antennas. A recent development, the Cassegrainian antenna, accomplished a low-noise characteristic with the double-reflector system shown in Fig. 7. In this arrangement, the feed horn is placed close to the vertex of the paraboloid so that it radiates in the same direction as the main paraboloid.

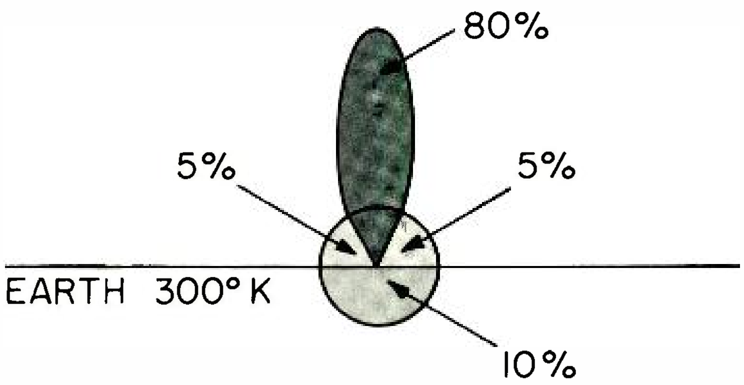


Fig. 6—Example of the evaluation of antenna temperature.

The "effective position" of the horn remains the same as in the classical arrangement shown in Fig. 5 (a hyperboloid reflects radiation as though emitted from the paraboloid focal point). This type of antenna allows the use of a very short transmission line, causes spillover to be directed away from the ground, and allows back lobe reductions to 1 percent of the total power. With this antenna, item 2 of table I, now becomes: 0.01 × 300°K = 3°K; thus, antenna temperature becomes only 25°K. Since the Cassegrainian antenna has its feed horn behind the reflector, the length of transmission line necessary to connect the duplexer and receiver to the antenna is drastically reduced. Mounting the duplexer and receiver at the horn location further reduces the transmission path.

Consequently, the combined use of the Cassegrainian antenna and refrigerated components in the transmission path reduces noise contributions of these circuits to the same order of magnitude as that of the antenna.

### CONCLUSION

The relative noise properties of different radar systems can be evaluated by using equation 13. Ten years ago, a typical system would have employed a mixer as the first receiver stage resulting in a receiver noise figure of about 10 db. The receivers were generally located far from the antenna feed, and gas tube duplexers with greater than 1 db loss were employed. Consequently, figures shown in Table II are typical of this era; they are used to calculate system noise temperature. It can be seen from Table II that the receiver contributed 96 percent of the total noise. Thus, there was little need for detailed knowledge or drastic reduction of the transmission line losses or the antenna noise.

A modern system would use a parametric amplifier as the first receiver stage producing a receiver noise figure as low as 2 db. A Cassegrainian antenna would reduce the antenna noise to about 25°K and the duplexer-paramp assembly mounted at the antenna feed further reducing the receiver losses to less than 1 db. Using these figures, the expected

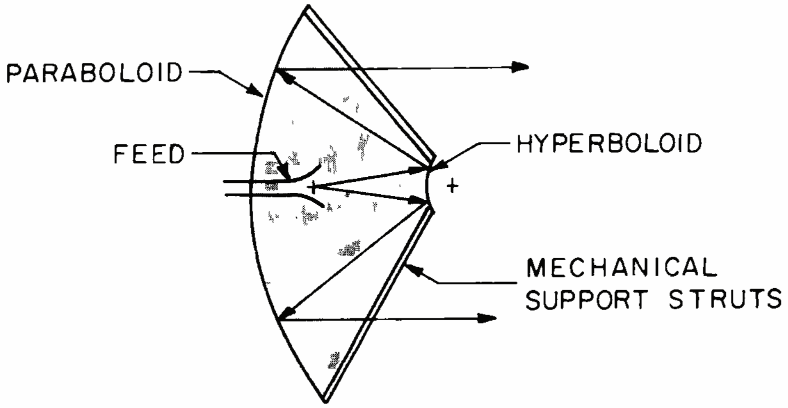


Fig. 7—Sketch showing arrangement of recently developed double-reflector cassegranian antenna.

**TABLE II—Typical Values, Early 1950's**

$T_A = 50^\circ \qquad L = 2\text{ db} \qquad NF = 10\text{ db}$

$T_p = 290^\circ\text{K} = T_o \qquad (\text{Ratio} = 1.59) \qquad (\text{Ratio} = 10)$

$T_s = T_A + (L-1)\,T_p + L\,(NF-1)\,T_o$

$T_s = 50 + (1.59-1)\,290^\circ\text{K} + 2\,(10-1)\,290^\circ$

$T_s = 50 + 17.1 + 5400$

$T_s = 5621^\circ\text{K}$

noise temperature is calculated in Table III. Here it is seen that the modern receiver contributed only 65 percent of the total noise. Therefore, future high-sensitivity antenna systems must concentrate design effort on the reduction of antenna noise and transmission line losses.

Further utility in using system noise-temperature concepts results when comparing a given system operation with two different receivers. Using the values of the modern radar example, it is interesting to see how system improvement results markedly when changing receiver noise factor ($NF$) from 2 db to 1 db. The new noise temperature $T_{s_2} = 25 + 75 + 91 = 191^\circ\text{K}$. Previously $T_{s_1} = 317^\circ\text{K}$. Hence, the sensitivity improvement $T_{s_1}/T_{s_2} = 1.65$, or 2.2 db.

Here it is shown that an improvement of 1 db in receiver noise figure results in an improvement of 2.2 db in radar sensitivity! This apparent anomaly results from the receiver noise figure being defined with a reference temperature of 290°K at its input, while in actual system operation the receiver has input noise-temperature different from 290°K. In fact, for the low-noise system in this example it is much less than 290°K.

The material presented and the method used in analyzing noise contributions have shown how the evolution of low-noise receivers created a need for a detailed knowledge of antenna and transmission line contributions to the over-all system sensitivity. The general expression, derived in this paper, provides a convenient means for comparing the noise performance of different antenna systems.

**TABLE III—Typical Values, Modern Systems**

$T_A = 25^\circ\text{K} \qquad L = 1\text{ db} \qquad NF = 2\text{ db}$

$T_s = 25 + 75^\circ\text{K} + (1.6-1)\,1.25\,(290)$

$T_s = 317^\circ\text{K}$

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James A. Luksch

George A. Verwys

# SERVO DESIGN FOR TRACKING RADARS

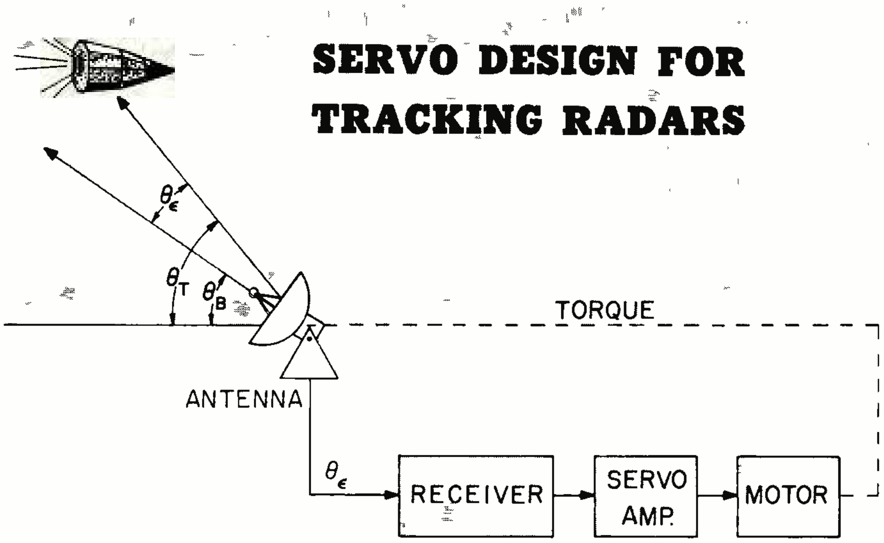

Fig. 1—Tracking system.

A tracking radar automatically follows a target by servo-controlled dynamic pointing of the radar antenna. The designer of such a servo system must satisfactorily answer these questions: How accurately must the radar track the target? What sources of error might affect this accuracy? What extremes of velocity and acceleration are imposed on the antenna by expected target motion? Answers are provided here with methods of design analysis, illustrated by examples from the design of the servo system for the AN/FPQ-6 tracking radar.

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A TRACKING RADAR must furnish information on the position of a target as a function of time. To do this, a servo system compares antenna-pointing angle with target angle—and uses the difference angle to drive the antenna in the direction of the target.

Ideally, the angular position of the target, in both elevation and azimuth, is the angular position to which the antenna is driven; however, sources of tracking error prevent this ideal from being realized. Certain sources of error are external to the radar hardware; *propagation error*, *multipath return*, and *target glint* are typical examples. Other errors are directly attributable to the radar system, and may be separated into various overlapping categories, such as random, repeatable, static, or dynamic errors. Errors may also be classified as follows, according to the part of the system in which they occur:

1) *boresight errors*, resulting from misalignment of the radar-beam axis and the antenna axis.
2) *pedestal errors*, resulting from lack of precision in the mechanical system.
3) *servo errors*, resulting from noise, dynamic lag, and load disturbance.

Considerations in this paper are limited to the discussion of servo errors and their effects on the design of the tracking radar.

### NOISE ERROR

Servo noise is defined as any component of output not present in the input, including a constant or slowly varying component (bias), and rapidly varying components, called jitter. Bias error may be caused by drifting component values or power supply voltages. A common cause of jitter is electrical pickup in the servo amplifiers; for example, intermodulation between the 60-cycle power (or its harmonics) and signals based on the system repetition rate, such as the angular error signal from the receiver or stray RF energy picked up and rectified in the servo amplifier.

Electrical-noise error can be minimized by careful servo amplifier and power supply design. Particular attention must be given to component stability and amplifier shielding.

The mechanical portion of the servo system also contributes to servo noise. Friction and gear backlash cause the antenna to move in jumps. Motors, electric and hydraulic, deliver a pulsating torque because of the finite number of commutator segments and pole pieces in the electric motor and the finite number of pistons in the hydraulic. Servo valves have a dead zone and exhibit hysteresis. Noise from these and other mechanical non-linearities can also be minimized by careful design.

### DYNAMIC LAG ERROR

Dynamic lag errors result from the fact that servos require a non-zero error in order to move. For a more precise concept of dynamic lag error, consider the block diagram of Fig. 1 showing only one axis. The input from the receiver to the servo amplifier is a signal of magnitude proportional to the difference between the true target position angle $\theta_T$ and the antenna beam angle $\theta_B$, and of polarity dependent on the sign of the difference (that is, whether the radar is leading or following the target). The difference $\theta_E = \theta_T - \theta_B$ is the error, and the proportional signal is the error signal.

Amplified error signal controls the direction and speed of the servo motor, driving the antenna in the direction of the target at a speed proportional to the error. When the error is reduced to zero, the antenna stops.

However, when the target is moving at a constant angular rate, an error signal of constant magnitude (a *velocity lag error*) is needed to drive the antenna at the same rate, that is, to track the target. Similarly, an *acceleration lag error* is needed to track an accelerating target. All time derivatives of motion produce corresponding errors, called *dynamic lag errors*.

Thus, dynamic lag error is inherent in servo operation, but must be confined to levels dictated by the requirements for the radar system. Dynamic lag errors can be reduced by increasing servo gain; with more gain, the antenna moves at a particular rate with a smaller lag error. There is a limit set by the phase shift of the system as to how much gain and bandwidth can be increased. A frequency exists at which the phase shift is 180°; when servo gain is too great at this frequency, the servo is unstable and system error causes the motor to run in the wrong direction (actually increasing the error). For stable operation, loop gain must be less than unity at the 180° phase-shift frequency.

### LOAD DISTURBANCE ERROR

Load disturbance errors are caused by such variations in the servo load as wind forces on the antenna, and improper counterbalancing of the antenna. Load disturbance error can be minimized by mechanical design, and by electronic compensation in the servo system.

### SERVO SYSTEM DESIGN

Servo system design for a tracking radar starts with specification of allowable servo errors, dynamic performance, antenna size, and wind loads. From this information, servo gain, bandwidth, and the power required from the motors can be determined. In the following paragraphs, general design analysis methods are outlined and illustrated by examples from the design of the azimuth servo for the AN/FPQ-6, a precision tracking radar, design parameters for which are shown in Table I.

### SERVO-MOTOR POWER, SPEED, AND TORQUE

The servo motor is selected by considering the maximum angular velocity of the radar, maximum acceleration, and rotational inertia of the load.

First, the total torque $T_t$, which is the sum of acceleration torque $T_a$, wind torque $T_w$, and friction torque $T_f$, is determined. For the AN/FPQ-6:

$$T_a = \ddot{\theta}_{\max} J$$
$$= (0.350)\ (34{,}000) = 11{,}950 \text{ lb-ft}$$
$$T_t = T_a + T_w + T_f$$
$$= 11{,}950 + 16{,}000 + 1{,}000 = 28{,}950 \text{ lb-ft.}$$

Knowing the peak torque and the maximum velocity, the peak horsepower can be calculated:

$$HP = \frac{(T_t)\ (V_{max})}{550}$$
$$= \frac{(28{,}950)\ (0.5)}{550} = 26.3 \text{ hp}$$

At this point, a tentative choice should be made among available types of drives: electric motor, pump-controlled hydraulic motor (A-B system), or valve-controlled hydraulic motor. Each has advantages and disadvantages in size, weight, cost and torque-to-inertia ratio. Having made a tentative choice, the gear ratio (the ratio of maximum motor speed-to-maximum antenna speed) can be determined.

**Table I—Design Parameters for the AN/FPQ-6**

| | |
|---|---|
| *Allowable servo errors* | |
| Maximum dynamic lag error | 2.0 mrad |
| Maximum noise error | 0.01 mrad |
| | (1 mrad = 1/1000 of a radian) |
| *Dynamic Performance* | |
| Maximum velocity, $V_{max}$ | 0.500 rad/sec |
| Minimum velocity, $V_{min}$ | 0.00001 rad/sec |
| Maximum acceleration, $A_{max}$ | 0.350 rad/sec$^2$ |
| *Antenna* | |
| Moment of inertia, $J$ | 34,000 lb-ft-sec$^2$ |
| *Wind Load* | |
| Maximum wind torque, $T_w$ | 16.000 lb-ft |

It was decided to use a hydraulic motor for the AN/FPQ-6 servo, chiefly because of the high torque-to-inertia ratio and small size characteristic of this type of motor. A valve control was chosen because it requires less oil under pressure than a variable flow-pump control. Both motor inertia and oil volume must be kept low, since these factors enter into the servo-stability or phase-lag problem.

After choosing the type motor, the gear ratio for the AN/FPQ-6 could be determined. The maximum recommended speed for a hydraulic motor of the power needed is 3600 rpm, or 375 rad/sec; maximum recommended intermittent speed is 440 rad/sec. The ratio of maximum motor speed to maximum antenna speed is 375 ÷ 0.500 = 750 on a continuous basis, or 440 ÷ 0.500 = 880 on an intermittent basis. For optimum low-speed operation, it is desirable to have the ratio as high as possible. A gear ratio of 718:1 was selected for the AN/FPQ-6. This gear ratio satisfied both servo and gearbox design considerations.

The motor must be able to deliver a torque equal to the peak load torque divided by the gear ratio, and accelerate its own rotational mass. The motor does not need to deliver a power equal to the product of peak torque and maximum speed continuously; instead, a duty cycle may be estimated, and a motor selected to deliver peak power in that duty cycle.

However, the motor must deliver any expected combination of torque and speed. For this purpose, consider a target as requiring the most adverse combination of torque and speed that the radar could be expected to track. Then, by examining torque-speed characteristics of motors of suitable size in relation to the torque-speed requirements of the typical target, a specific motor can be selected to meet the requirements. In the initial design, the motor torque should be made large enough to allow for changes in load inertia (which invariably increases above the original estimate).

In designing the AN/FPQ-6 servo, the typical target was a ballistic target flying a horizontal course at a velocity of 2 miles/sec at an altitude of 50 miles.

The azimuth axis of the antenna tracks the target in the azimuth plane; so in effect, the radar tracks a point on the ground directly under the actual target. Azimuth velocity, therefore, is a function of elevation angle, set at 85° for the AN/FPQ-6, so that the azimuth velocity would approach the maximum specified velocity of 0.500 rad/sec. The peak velocity occurs at the point of nearest approach to the radar; at 85° elevation, velocity is 0.450 rad/sec.

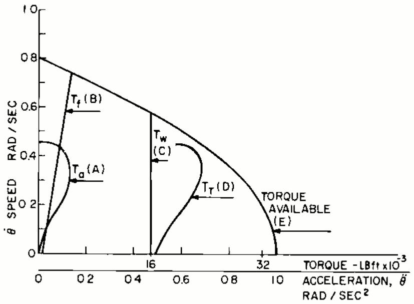

Fig. 2—Torque-speed characteristics.

For the horizontal crossing target, the following equations can be written for azimuth position and for derivatives with respect to time:

$$\theta\ (t) = \arctan at$$

where,

$$a = \frac{\textit{velocity of target}}{\text{minimum ground range}} = 0.450$$

$$\dot{\theta}\ (t) = \frac{a}{1 + (at)^2} = \frac{0.450}{1 + 0.20\ t^2}$$

$$\ddot{\theta}\ (t) = \frac{-2\ a^3 t}{(1 + a^2t^2)^2} = \frac{-0.18t}{(1 + 0.20\ t^2)^2};$$

$$\dddot{\theta}\ (t) = \frac{-2a^3(1-3a^2t^2)}{(1 + a^2t^2)^3} = \frac{-0.18\ (1-0.60t^2)}{(1 + 0.20t^2)}$$

Where $\dot{\theta}$. $\ddot{\theta}$, and $\dddot{\theta}$ indicate the first, second and third time derivatives, respectively, of the azimuth angle.

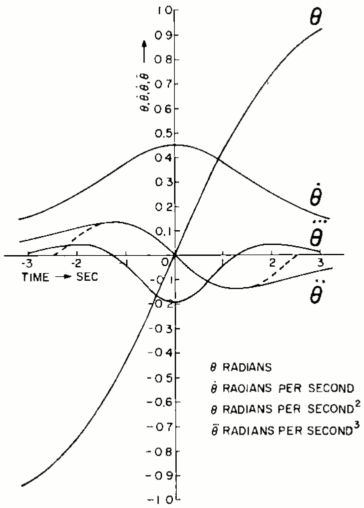

Fig. 3—Azimuth component of a crossing target.

Curve A of Fig. 2 shows azimuth velocity $\dot{\theta}(t)$, plotted against azimuth acceleration, $\ddot{\theta}(t)$. Since the acceleration torque is directly proportional to acceleration ($T_a = J\ddot{\theta}$), a torque scale can be placed on the graph, and Curve A can be considered as a plot of $\dot{\theta}(t)$ versus $T_a$. Curve A then represents the *acceleration torque* which must be available at any velocity.

*Wind torque*, Curve C, and *friction torque*, Curve B, must be added to acceleration torque. Thus, Curve D shows the *total torque* required of the motor for the example. Curve E is the torque-speed characteristic for the hydraulic motor and gearbox selected for the AN/FPQ-6 servo. The torque required is well below the total torque available.

## SERVO DYNAMIC PERFORMANCE

Servo dynamics involves servo stability and required gain parameters. To determine the servo gain required, the typical target is again considered in which motion derivatives are plotted with respect to time (see the velocity, acceleration, third derivative curves of Fig. 3). This family of curves is approximated by sinusoids, which can be converted to position sine curves by integrating the appropriate number of times. These position sine waves represent the input to the servo system. A servo must follow an input having the frequency and amplitude of each of these position sine waves within the allowable lag error to be capable of tracking the actual target.

The minimum required servo gain at each of these frequencies can be found by dividing the amplitude of the appropriate position sinusoid by the maximum allowable servo error. A servo having more than the calculated gain at each of these frequencies will be satisfactory.

In the AN/FPQ-6 servo dynamic analysis, the typical ballistic target at 2-miles/sec velocity and 50-mile altitude was used. Fig. 3 shows $\theta$, $\dot{\theta}$, $\ddot{\theta}$, and $\dddot{\theta}$ for this target plotted against time.

As an example of the calculation of servo gain, consider the acceleration curve, $\ddot{\theta}(t)$. The sine-wave approximation to this curve has an amplitude of 0.136 rad/sec$^2$, and a frequency of 0.2 cps. The corresponding position sinusoid, found by two successive integrations, has the same frequency and an amplitude of 0.087 radians. To keep servo lag error less than the specified maximum of 2 milliradians, the servo gain must be greater than 32.5 db. The sinusoids for position, velocity, and the third derivative, and the gain required at each frequency, are found in a similar manner.

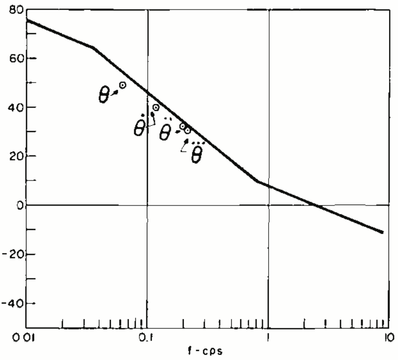

Fig. 4—Servo loop gain in db versus frequency.

Fig. 4 shows the gain-vs.-frequency characteristic evolved for the AN/FPQ-6 servo loop. Fig. 4 also shows the calculated values of gain for the $\theta$, $\dot{\theta}$, $\ddot{\theta}$, and $\dddot{\theta}$ sinusoids. The open-loop gain characteristic is above all of these points.

For satisfactory stability, the total phase lag at the frequency of unity gain must be less than 145°, approximately. This phase lag imposes requirements on the antenna mechanical system (pedestal). Resonant frequencies of the distributed mass and the distributed stiffness of the pedestal must be high enough to avoid contributing to the total phase lag in the servo system. At the same time, the mechanical system must be strong enough to withstand the forces exerted by the servo system and the wind.

Fig. 4 shows that the frequency of unity gain for the AN/FPQ-6 servo is 2.5 cps, resulting in a closed-loop bandwidth of approximately 5 cps. For servo stability at this bandwidth, the resonant frequency of the AN/FPQ-6 pedestal must not be less than 15 cps. To be sure that the resonant frequency would not be below this level, it was decided to use two motors and gear trains, thus doubling gear train stiffness.

Other pedestal characteristics affecting servo-dynamic performance are nonlinearities such as sticking and sliding friction, and backlash. To achieve a high-accuracy radar, particular attention must be paid to minimizing all these factors. In the AN/FPQ-6, for instance, preload motors apply an opposing torque to the two gear trains to eliminiate backlash.

## AN/FPQ-6 DESIGN HISTORY

Actual design of the AN/FPQ-6 servo was accomplished in four stages. First, the analysis of motor power, speed, torque, and of dynamic performance were carried out just as described.

Next, the characteristics of the servo system, with the best estimate of nonlinearities, were programmed on an analog computer, and the preliminary design checked.

In the third stage, a servo simulator was built and tested. This simulator consisted of actual valves, motors, preload motors, and hydraulic pump, combined with simulated load inertia and gear stiffness. The simulator test is much more significant than the computer test, because actual non-linear elements are used rather than estimated values.

The final servo design occurred during tests of the pedestal and antenna hardware. This stage is very important since no calculation or simulation can give the true amplitude and phase response of the pedestal, a major factor in servo stability.

## ACKNOWLEDGMENT

The author wishes to express his appreciation to George F. Watson for his invaluable assistance in editing and proofreading the manuscript.

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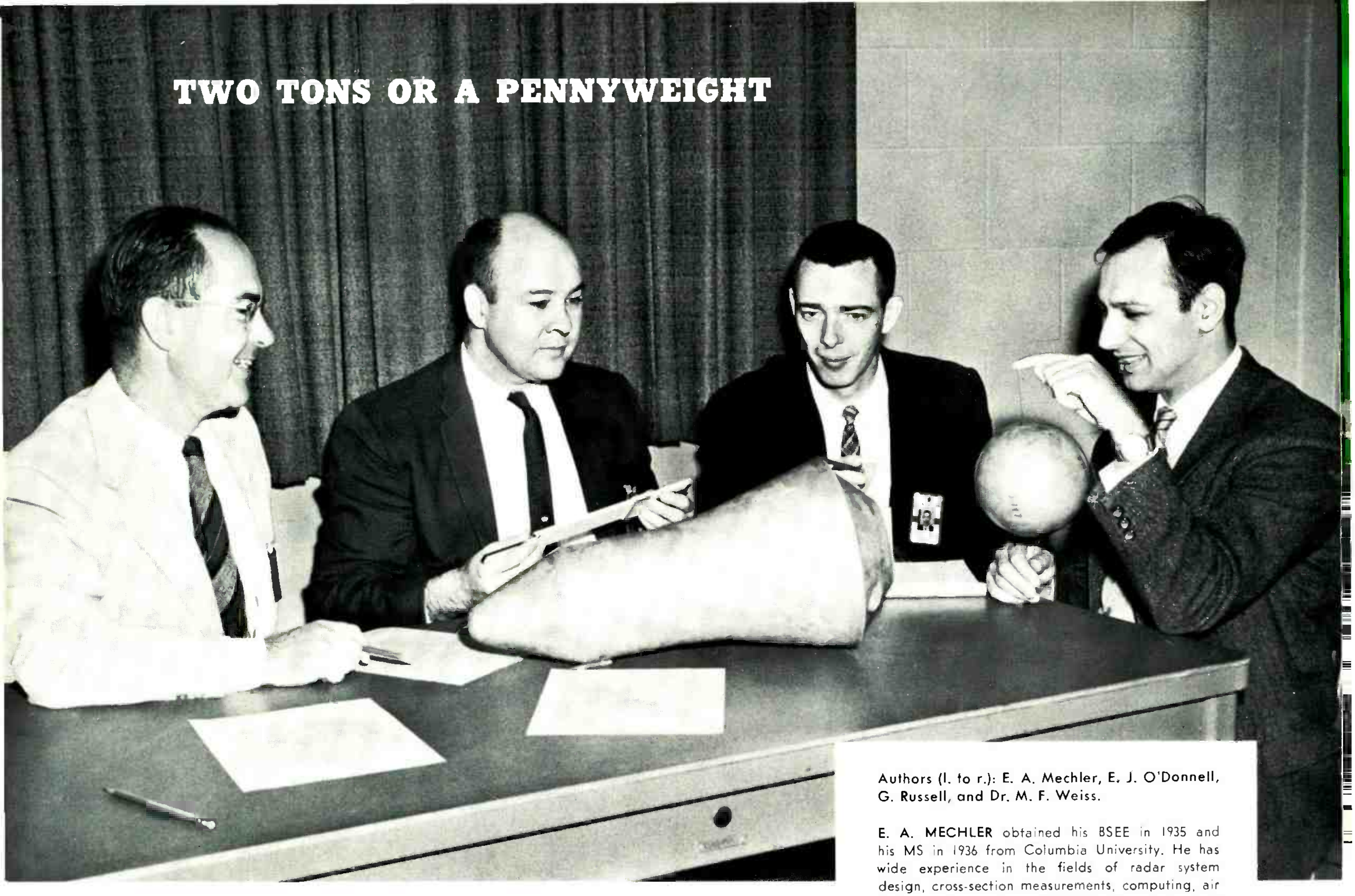
# TWO TONS OR A PENNYWEIGHT



Authors (l. to r.): E. A. Mechler, E. J. O'Donnell, G. Russell, and Dr. M. F. Weiss.

"Two tons or a pennyweight" describes the capability of the radar cross-section measurement range located at the Electromagnetic Research Laboratory (ERL) of the DEP Moorestown Missile and Surface Radar Division. It is a unique capability—the only range in the United States that can accurately determine the radar cross-section of objects as large as a truck, or as small as a penny. This paper describes the work being done at this ERL range.

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THE TERM *radar cross section* describes that characteristic of a body which causes the distribution of scattered radar energy in space. Cross-section is a function of the object's shape, and the object's orientation with respect to the radar, the surface material of the body, the radar frequency, and the polarization. It is the purpose of a radar cross-section measurement range to determine the relations among the various parameters for relatively complex body shapes.

### MECHANICAL SYSTEM

A good cross-section measurement range must obtain data under essentially free-space conditions, with background noise emanating from the range-and-target support structure amounting to only a small fraction of the energy reflected from the target. In addition, the target object should be illuminated by a plane wavefront of uniform intensity. The mechanical support arrangement must permit precise and repeatable positioning of the target, and contribute little or nothing to the background cross section. The cross-section measurement range at ERL has been laid out with the above objectives in mind (Fig. 1). The general guidelines for obtaining low range-background were to illuminate a small

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ground area at the lowest intensity possible and position all non-target objects so that they would not reflect microwave energy back to the radar.

To obtain a simple and accurate target support structure, the targets rotate on a vertical shaft rigidly supported by an enclosure of minimum radar cross section; the target plane of rotation would contain the radar RF axis. Design of the range was then approached in the following steps:

1) *Determination of Antenna to Target Distance:* As length of the range increases, the illuminating wavefront approaches the plane-wave configuration of free space. However, for a given beamwidth, determined by antenna dimensions and wavelength of radiation, increase in range also results in a greater illuminated ground area around the target. Following the usual practice, a wavefront (flat within 1/16 wavelength) was chosen, giving the well known $2D^2/\lambda$ criterion for the minimum length of range: about 1750 feet for a 12-foot target length $D$ and a 2-inch wavelength $\lambda$.

2) *Minimizing Ground Returns:* Ground illumination in the target area was minimized by proper choice of dish size, range gating, and by raising the radar line-of-sight above ground level. Returns from the portion of the ground within the radar gate were further reduced by smoothing the earth surface—and placing this surface in the shadow of a row of screens, or radar fences. Thus, the target area is illuminated at a reduced intensity.

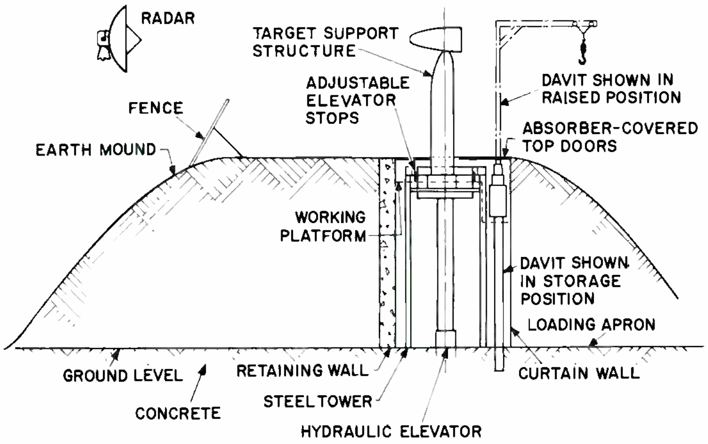
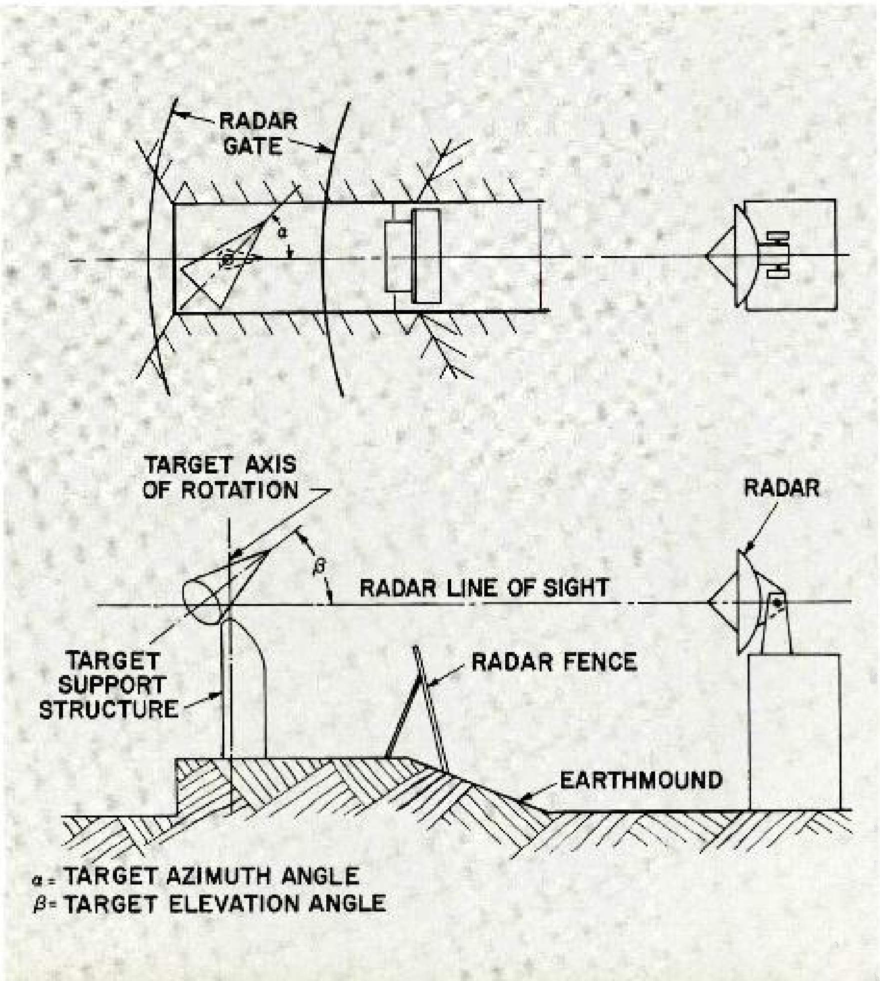


Fig. 2—Target support site where the target loading equipment is utilized.

Fig. 1—Arrangement of the Electromagnetic Research Labs' (ERL) cross-section measurement range.



3) *Object Support Structure:* To obtain a minimum of energy reflected from the object support structure, it was covered with microwave absorber and shaped as a symmetrical airfoil with the sharp edge directed toward the radar. The width of this structure was held to a minimum; height was kept to a reasonable value by placing the structure on a hill, whose long dimension was directed along the radar line-of-sight.

The presence of the shielding screens and the ground itself cause an undesirable variation in the intensity of the target illuminating radiation. However, by proper vertical positioning of the target and screens the target was put in an area of uniform intensity of illumination.

Mechanical design of the RCA range had to satisfy all of the above requirements. The outdoor range was designed to permit testing of targets up to 4000 pounds in weight and 15 feet in length; further, it was required that loading of targets must be a fast and safe operation.

Basically, the support site arrangement (Fig. 2) consists of an earth mound and an elevator-mounted target support structure that is able to rotate the target object at speeds up to ½ rpm. When the range is not in use, the target support structure and the associated loading davit or crane are stored in the enclosed space at the rear end of the mound; this storage space is formed by the concrete retaining walls, the absorber-covered top doors, and a curtain wall.

Loading of heavy targets is accomplished with the aid of the loading davit; on opening the hydraulically operated top doors, the davit is raised to a working position, and rotated to pick up the target object from the loading apron. With the elevator-mounted support structure remaining in the retracted position, the davit transfers the target onto the support structure. The davit is then returned to storage position, the elevator raised to test position as determined by adjustable stops and the top doors closed to blend smoothly into the surface of the earth mound.

Safety aspects have been stressed in the design of the facility. Choice of a hydraulic elevator system, built-in work platforms, numerous mechanical and electrical interlocks, as well as centralized push-button controls contribute to safe and efficient operation.

### ELECTRONIC SYSTEM

The radar cross-section measurement range is set up for C-band operation (5400 to 5900 Mc). The ERL laboratory-type environment combined with the outdoor-range facility permits cross-section measurements to be performed under well-controlled test conditions. The electronic system is designed especially for cross-section operation; circuits are reliable, stable and adaptable for changes in the state of the art. Such factors also provide for ease in maintenance and economical operation.

The transmitter consists of a QK447 magnetron oscillator continuously tunable over a frequency range of 5400 to 5900 Mc. Peak power is 2.5 kw with a pulse width of 0.19 ± 0.01 $\mu$sec and a pulse repetition frequency of 1 kc. The line-type modulator employs a hydrogen thyratron as the switch tube, with a shunt diode circuit to absorb excess reflections. An isolator is provided between the magnetron and the waveguide to minimize frequency pulling caused by the line effects. A power splitter is used to divide the magnetron output equally between the two transmitting channels with an accuracy of ±0.25 db; then the divided signals are radiated orthogonally in space and, to obtain the transmitted polarization desired, may be shifted in phase relative to each other over a range of 360°.

The return signal is mixed, amplified, and then detected in a gated IF amplifier. The AGC voltage, developed to maintain the detected signal constant, is a measure of signal level in the range gate or target return; this AGC voltage is then plotted against cross section in decibels relative to one square meter. The cross section in this form is recorded on Scientific-Atlanta Polar and Rectangular Antenna Pattern Plotters which are driven synchronously by the target's rotation. The output of this data recording system is in the form of the log of the target cross-section versus the aspect angle of the target.

### MEASUREMENTS

When measurements are made on radar targets, the patterns depend on the target, the radar, and the range. In preceding paragraphs, emphasis is given to the elimination of distortion in the radar pattern during design of the range and radar. In this section, typical patterns associated with targets of simple geometrical shape are described; such patterns are useful in the calibration and study of the outdoor radar cross-section range.

Since it is completely symmetrical, the simple body shape of the sphere presents the same radar cross section when viewed from any aspect angle. When this constant return is plotted on a polar graph as a function of angle, the pattern should be a circle (Fig. 3). The actual plot is not a true circle, since distortion caused by the background is purposely introduced for reasons discussed later.

Other objects such as flat plates, cylinders and cones also have typically standard patterns. The formulae for these patterns are developed in detail in the references. Table I lists the formulae for the maximum cross-section amplitude due to a specular reflection of energy from particular surfaces.

For these simple shapes the maximum return occurs when the radar line-of-sight is normal to the surface of the body. As the aspect angle is varied continuously, the cross section will fluctuate presenting a resultant lobed pattern, unlike the typical pattern for a sphere. The measured pattern for the cylinder of Fig. 4 approaches the $(\sin X/X)^2$

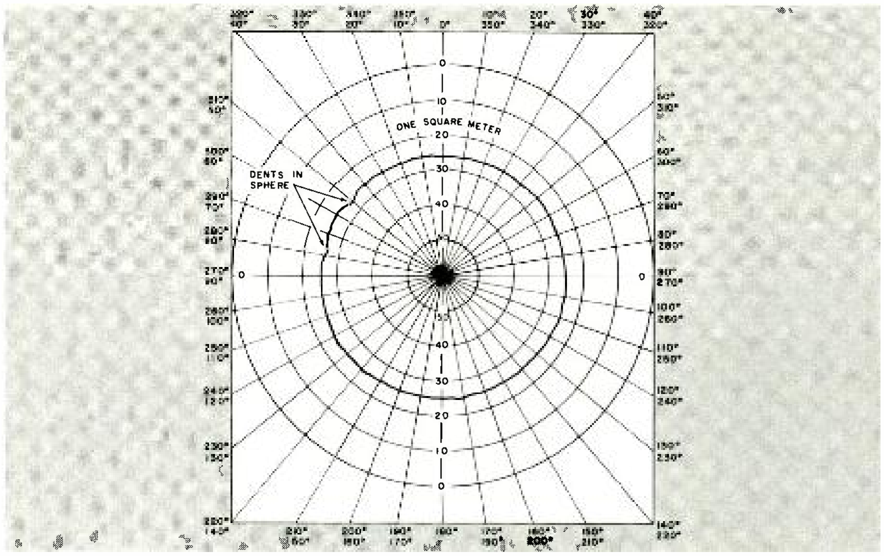
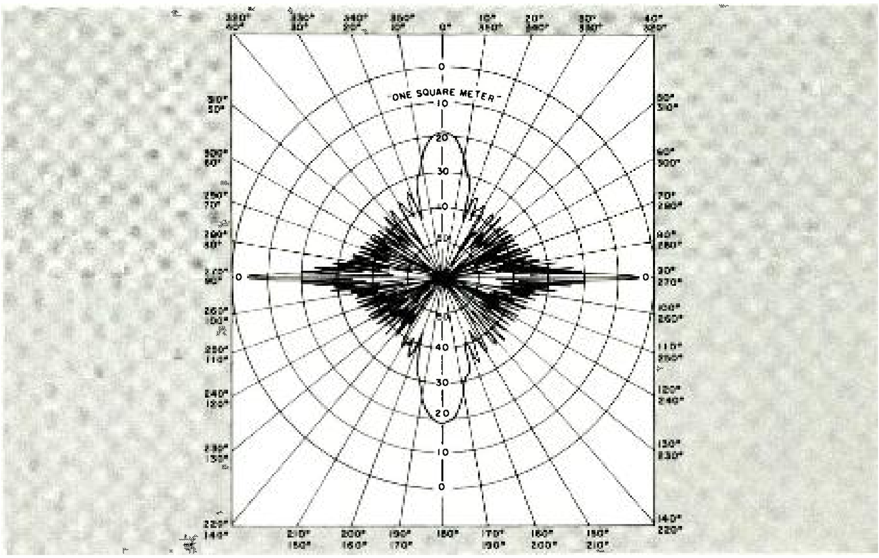


Fig. 3—Typical pattern for a 2-inch spherical body shape. Note that some distortion has been purposely introduced.

Fig. 4—Typical pattern for a 5-inch cylinder which approaches a $(\sin x/x)^2$ function.



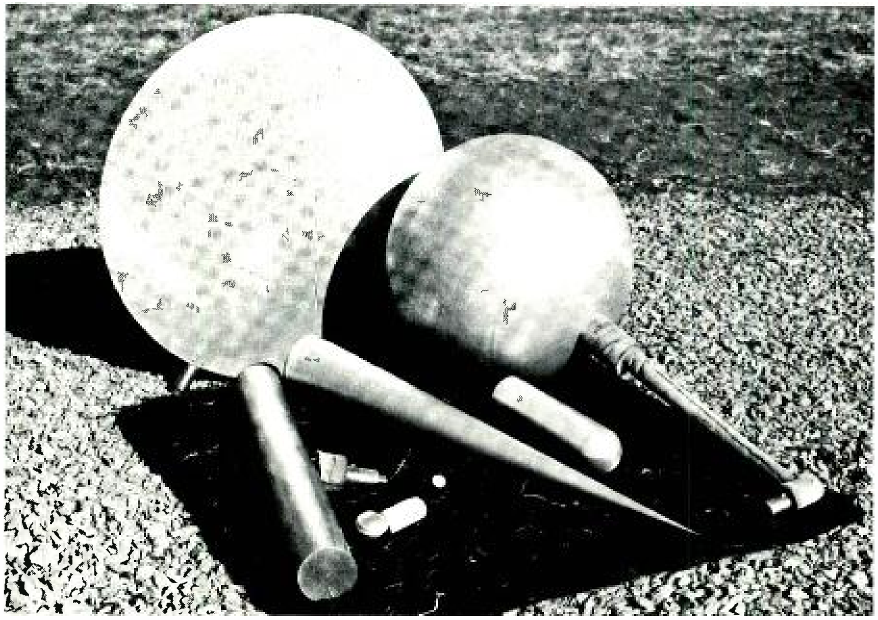


Fig. 5—Some of the calibration and evaluation targets used at the ERL range.

function, a standard pattern in which the ratio between the amplitudes of consecutive peaks is fixed by the function and not by body dimensions. However, since the theory assumes a cylinder of infinite length, there will not be complete agreement between calculated and measured patterns. The same is true for the flat-plate pattern except that the function is the first-order Bessel function listed in Table I. The pattern on the side of the cone is more complex; on the side of the specular point toward the base, the pattern is similar to that from a cylinder; on the side toward the nose, the pattern drops off more sharply and the lobes are much narrower. Thus, each of these bodies has a characteristic pattern which allows it to be identified.

Dimensions of the body can be obtained in two ways. Once the shape has been determined, the dimensions can be calculated from the maximum radar cross section and the formula listed in Table I. The width of the main lobe $W$ also is a key to maximum body dimension, where $W$ (in radians) $= \lambda/L$. The side lobes are half the width of the main lobe, and so they too can be used in analysis.

These fixed characteristics of the radar cross-section pattern are useful in the evaluation of the range. First, the amplitudes of the maximum return can be calculated and used to calibrate the recording of the pattern in terms of absolute radar cross section, and second, the side-lobe patterns can be calculated for flat plates and cylinders and compared with measurements to indicate range problems. If the range is not perfect, these patterns are distorted, and this distortion is then a measure of the range imperfection. This imperfection does not, however, make the range inoperable. Determination of the sources of error and their magnitudes allows for the proper analysis of the data. For example, in Fig. 3, neglecting the sphere surface anomalities, a variation of approximately 1 db can be observed in the sphere pattern. This distortion is deliberately caused by rotating the sphere eccentrically so that the center of the sphere changes in range from the radar. Since the source of the interfering background signals remains fixed, the resultant signal to the radar is the sum of two signals, constant in amplitude, but with one signal varying slowly in phase. The amount of distortion measured therefore, is an indication of the amplitude of the background under test conditions, with a target emplaced.

Not all of the radar energy striking the target is returned on a direct path to the radar or lost. Some of it interacts with the background or the target support, resulting in assymmetrical pattern distortions. Cylinder and flat plate patterns are used in much the same way as the sphere mentioned above, to locate and eliminate these interaction or "multipath" problems. Fig. 5 shows some of the calibration and evaluation targets in use at the ERL range.

## CONCLUSION

While some problems are still existent, concerted efforts are being directed toward determining new techniques of target mounting and measurement which will maintain the capability of RCA's unique radar backscattering cross-section measurement range.

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**TABLE I — Radar Cross Section Formulae**

| *Body* | *Radar Cross Section* | *Side Lobe Patterns* |
|---|---|---|
| Sphere: | $\sigma_S = \pi r^2$ | None |
| Flat Plate: | $\sigma_P = \frac{4\pi A^2}{\lambda^2}$ | $\left[\frac{2\,J_1\,(U)}{U}\right]^2$ |
| Cylinder: | $\sigma_C = \frac{2\pi r L^2}{\lambda}$ | $\left(\frac{\sin X}{X}\right)^2$ |
| Cone Side: | $\sigma_P = \frac{8\pi L^3}{9\lambda} \quad \frac{\text{Sin}\alpha}{\text{Cos}^4\alpha}$ | |

Where: $\sigma$ = radar cross section (subscript denotes body)
$r$ = radius
$A$ = area of flat plate
$\lambda$ = wavelength
$L$ = length of cylinder or slant height of cone
$\alpha$ = half angle at apex of cone
$J_1$ = first order Bessel function
$(X)$ = function of angle of rotation
$(U)$ = function of angle of rotation

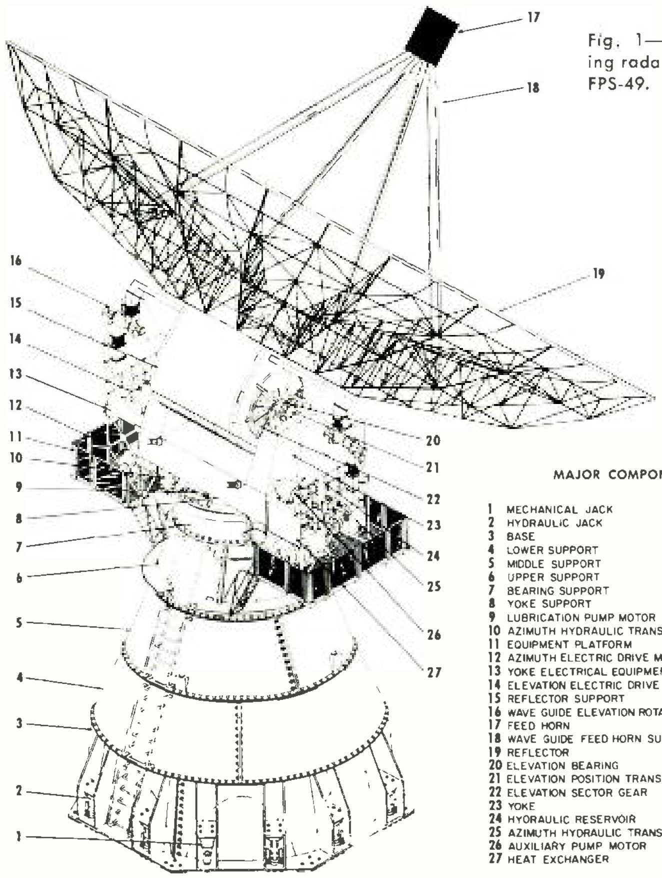

Fig. 1—BMEWS tracking radar antenna, AN/FPS-49.

MAJOR COMPONENTS

| | |
|---|---|
| 1 | MECHANICAL JACK |
| 2 | HYDRAULIC JACK |
| 3 | BASE |
| 4 | LOWER SUPPORT |
| 5 | MIDDLE SUPPORT |
| 6 | UPPER SUPPORT |
| 7 | BEARING SUPPORT |
| 8 | YOKE SUPPORT |
| 9 | LUBRICATION PUMP MOTOR |
| 10 | AZIMUTH HYDRAULIC TRANSMISSION (B-END) |
| 11 | EQUIPMENT PLATFORM |
| 12 | AZIMUTH ELECTRIC DRIVE MOTOR |
| 13 | YOKE ELECTRICAL EQUIPMENT |
| 14 | ELEVATION ELECTRIC DRIVE MOTOR |
| 15 | REFLECTOR SUPPORT |
| 16 | WAVE GUIDE ELEVATION ROTARY JOINT |
| 17 | FEED HORN |
| 18 | WAVE GUIDE FEED HORN SUPPORT |
| 19 | REFLECTOR |
| 20 | ELEVATION BEARING |
| 21 | ELEVATION POSITION TRANSMITTER |
| 22 | ELEVATION SECTOR GEAR |
| 23 | YOKE |
| 24 | HYDRAULIC RESERVOIR |
| 25 | AZIMUTH HYDRAULIC TRANSMISSION (A-END) |
| 26 | AUXILIARY PUMP MOTOR |
| 27 | HEAT EXCHANGER |

# MECHANICAL DESIGN OF LARGE PRECISION TRACKING ANTENNAS

Recent plans for large precision tracking antennas of the parabolic reflector type include complex feed arrays, very high antenna gain, and very low side-lobe levels. Scanning, acquisition, and tracking considerations necessitate high rotational velocities and accelerations, precise positioning, and accurate angle-data readout on the target position. These requirements, and scale effects due to the large antenna size, necessitate much greater emphasis on certain design concepts, as discussed herein.

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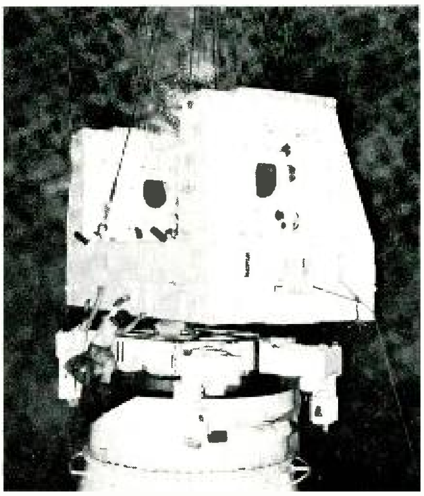

Fig. 2—Azimuth drive system.

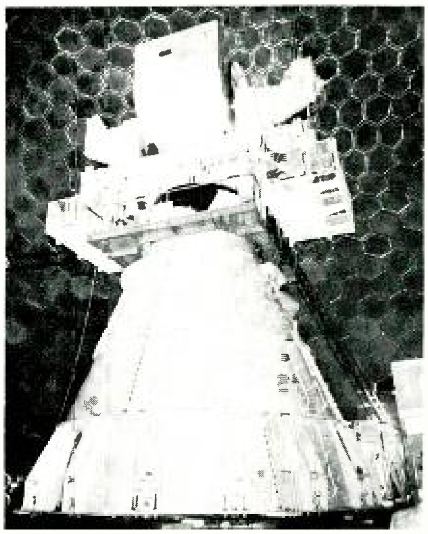

Fig. 3—Pedestal leveling-jack arrangement.

Fig. 4—Theodolite used for measuring reflector contour.

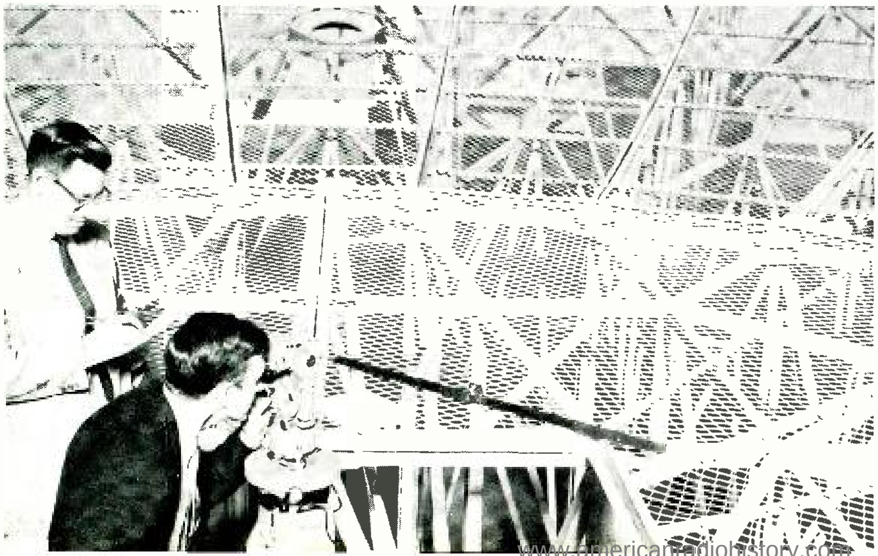

Fig. 5—84-foot antenna reflector.

FOUR DESIGN CONCEPTS of special importance to large antenna structures are: 1) *subdivision*, the division of the equipment into convenient assemblies, subassemblies, and components; 2) *adjustment*, utilization of adjustment in place of overly precise machining; 3) *compensation*, utilization of opposing trends to cancel each other; 4) *optimization*, study of trends to determine the best combination of parameters.

### SUBDIVISION

Conventional practice in designing and manufacturing small antennas involves dividing and subdividing the assembly into subassemblies, components, parts and pieces which are assembled, tested, and shipped as a single assembled unit. Larger antennas are partially disassembled and shipped as a few major subassemblies. When tracking antenna apertures reach the order of 100 feet, a number of causes combine to require a much greater subdivision of the antenna structure. These causes are not unique to large antennas, but differ considerably as to degree of effect. Facilitation of design, improved performance, and transportation limitations are examples.

The large antenna must often compete with its smaller brother with regard to acceleration performance, even though antenna inertia tends to increase as the fifth power of the antenna aperture. The resulting requirement on antenna drive torque, aggravated by transportation and machining limitations, leads to a major drive gear problem. Transportation and machining capacities tend to limit drive-gear diameters, while structural deflections limit the practical gear face width. The use of parallel drives with controlled load division permits conventional gear design.

Both machining and transportation limitations have a large effect on the design of large antennas. Except for greatly reducing the number of sources of supply, machining capacity is not the controlling item. *Transportation restrictions, both during and after fabrication, have more effect on the design than any other single factor.* If special routing and permits are to be avoided, state highway regulations on truck transportation are the most restrictive, although most other means of transportation are only slightly less restrictive. A package size of 8 feet wide by 7 feet high by 33 feet long is about the maximum size which is universally acceptable by all means of transportation. Special handling and routing will add nearly 3 feet to each of these dimensions, but this does not significantly reduce the parts into which a large antenna structure must be subdivided for transportation.

Fig. 1 shows an 84-foot-diameter tracking antenna (the BMEWS AN/FPS-49). The main structure consists of four assemblies: the pedestal, the yoke, the reflector support, and the reflector. Superimposed on the main structure are a number of installation subassemblies which add the azimuth and elevation drive transmissions, the azimuth and elevation data gear boxes, the electrical system, the microwave system, the hydraulic drive system[1] and the lubrication system. This breakdown of subassemblies permitted a team of designers to handle the design of each special area, with a maximum of efficiency.

The pedestal shown on the bottom of Fig. 1 illustrates the great degree of subdivision required to meet transportation restrictions. The pedestal is essentially a hollow conical shell, some 30 feet wide at the base, 35 feet high, and 10 feet in diameter at the top. Primarily for transportation reasons, this component was broken down into fifteen smaller pieces, each about 5 tons.

The azimuth drive (Fig. 2) consists of four identical (except for right and left hand) drive-gear boxes and motors. The use of parallel drives quadruples the torque capacity and permits using 10-inch-diameter pinions mating with a 128-inch-diameter gear with a 6-inch face width.

### ADJUSTMENT

It is well known that antenna electrical performance depends on holding reflector contour errors to a small fraction of a wavelength and that pointing accuracy requires minimization of structural deflections and mechanical errors. It is not so well known that proportionally increasing or scaling the dimensions of a given structure results in a general tendency toward increasing structural deflections and reducing mechanical performance. For example, it can be readily shown that doubling the dimensions of a simply supported beam loaded by its own weight will result in quadrupling the deflection at the center of the beam, doubling the tensile stress at the outer fibers of the beam, and halving the resonant frequency. The combined result of such "size effects," over-all accuracy requirements, and the extreme degree of subdivision required by transportation restrictions, is to produce a severe surface tolerance requirement. Holding increasingly tighter manufacturing tolerances would result in prohibitive costs. In nearly all cases, some form of adjustment-at-assembly can be provided which will allow use of conventional fabricating tolerances on individual parts and still produce the required over-all accuracy for the assembly.

Fig. 5 shows the BMEWS tracking-antenna reflector (AN/FPS-49) which utilizes 24 outer parts or sectors which are fabricated by conventional techniques using welding, drilling and screening fixtures to provide the required surface accuracy within each sector and maintain interchangeability of sectors. These 24 sectors are positioned relative to the center hub at the initial factory assembly and provided with the correct number and thickness of spacers to maintain the required spacing between each sector and the adjoining parts of the hub and adjacent sectors. Alignment of the sectors is measured by means of a theodolite located slightly forward of the apex of the reflector in the center of an access opening provided for microwave component maintenance (Fig. 4). Each sector is provided with five targets at known radii from the reflector axis. The theodolite is centered by measuring in from the edges of the center hub and "leveled" with respect to the center hub by sighting on points around the edge of the hub until the shift in elevation angle read from the theodolite is minimized. The theodolite is then utilized to determine the location of each check point on the sectors, by measuring elevation angle and computing the height of each point relative to the apex of the reflector. All of the sectors are first loosely bolted to the center hub. The sectors are then individually aligned relative to the hub using spacers between the sector and the hub. The joints between adjacent sectors are then fitted with spacers and the bolts tightened. After completing the assembly and bolting procedure, the entire reflector contour is again measured.

A second example of adjustment is shown in the lower part of Figs. 1 and 3, which show the leveling arrangement for a 180-ton tracking antenna. In this example, the real need for leveling is a result of possible foundation settlement, rather than because of tolerance build up. The complete antenna assembly is positioned for leveling by three mechanical screw jacks triangularly located around the pedestal base. Leveling is carried out in conventional fashion utilizing a precision level on the azimuth rotating assembly to determine when the azimuth axis is plumb. Thirteen hydraulic jacks are positioned around the pedestal base between the mechanical jacks. These hydraulic jacks are hydraulically interconnected and the hydraulic pressure is maintained so as to equally share the total weight on all sixteen jacks. This arrangement greatly reduces deflection or "sag" of the pedestal structure between the mechanical screw jacks and speeds up the leveling operation.

After the pedestal is leveled, 32 threaded adjustable spacers are snugged up against the pedestal base flange, the anchor bolt nuts are tightened, the 16

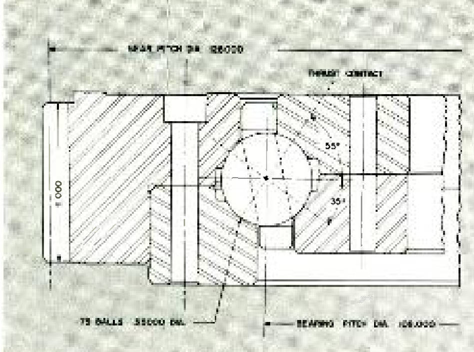

Fig. 6—Sectionalized view of BMEWS azimuth bearing.

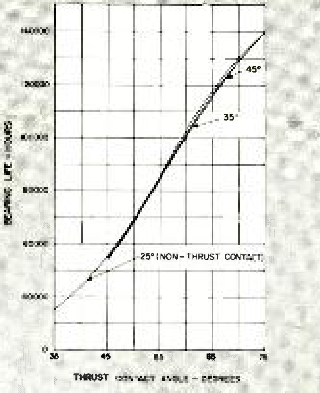

Fig. 7—Plot of bearing life versus thrust contact angle.

jacks are retracted, and the level measurement rechecked.

### COMPENSATION

Partial compensation of errors occurs naturally on a statistical basis whenever two errors happen to be 180° out of phase. Careful design of structural masses and compliances can cause one error to completely cancel the effect of a second error. Complete cancellation requires exact control of both magnitude and phase of two errors and can rarely be achieved. However the contribution of some of the larger errors can be greatly reduced by partial compensation.

Antenna feed deflections can be controlled so as to cancel the effect of reflector deflections. Both feed and reflector deflections tend to vary as a function of elevation angle, but the resultant effects on the location of the antenna beam axis are opposite in direction. Since the reflector deflections cannot be completely eliminated, the deflection of the feed support system is controlled so as to cancel the effect of the reflector deflection on pointing accuracy. This method of compensating feed and reflector deflections was utilized on the BMEWS tracking antenna. The reflector design was predicted primarily on strength and resonant frequency criteria. Feed supports were designed so the effect of feed deflections would cancel the effect of reflector deflections. Measurements at final assembly indicated that 82-percent compensation was achieved.

### OPTIMIZATION

Optimization of the design is always desirable and is usually practiced within broad limits. Very detailed optimization of the design becomes a necessity when the limits of conventional techniques are approached or surpassed. The mechanical design of large precision tracking antennas requires detailed considerations for optimum configuration in many of its concepts. The development of a large azimuth bearing is utilized as an illustration of the use of optimization.

The initial design study and layouts delineated the minimum size configuration of the antenna pedestal and azimuth bearing support. A four-point-contact ball bearing with a ball pitch diameter of 9 feet was selected. Conventional optimization led to the determination of several variables. Metallurgical factors determined the ball size at 3½ inches diameter, field experience with 53-percent-curvature conformity ($r/d = 0.53$, where $r$ = race radius and $d$ = ball diameter) fixed the radius of race curvature, and ball-retainer considerations established the total number of balls at 75 maximum.

The bearing life can be calculated if the forces on each ball resulting from the combination of axial, radial, and overturning loads are known. Determination of these forces for a particular contact angle combination requires the solution of three non-linear simultaneous equations. In order to establish the optimum internal configuration of the bearing, fifteen contact angle combinations were studied and the computations were carried out on a digital computer programmed for this purpose. The results are shown in Fig. 6.

The 55° and 35° contact angle combination was selected. The calculated bearing life was satisfactory and the design configuration allowed good design practice for the bearing retainer. Also, for this particular combination, the race depths could be designed to completely retain the pressure ellipses within the race confines.

The bearing design was further optimized based on the knowledge that the calculated life is obtained from extrapolation of fatigue data. The fatigue life of the bearing is a statistical function of the fatigue lives of all its components. The ability of the bearing to attain the calculated life depends to a great degree upon the precise control of material, metallurgy, heat treatment, and processing techniques. A detailed metallurgical specification was developed jointly with the bearing manufacturer for both the bearing rings and ball bearings in order to assure realization of the predicted performance of this optimum bearing design shown in Fig. 7.

### CONCLUSIONS

The design concepts that were discussed in this paper are considered to be of particular importance in large precision tracking antennas. The combined effect of large structures, rapid rotational motions, precise positioning, accurate reflector contour, and accurate data read-out result in stringent requirements on mechanical design of large antennas. Achievement of the desired goals requires a shift of emphasis on the conventional design considerations and the recognition that, occasionally, standard practices may be insufficient and must be abandoned. The particular techniques discussed herein are by no means limited to those areas where examples have been cited. Any large antenna design program must utilize all available facilities to meet the unprecedented requirements of antenna systems now in the planning stage.

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Paul Levi

Wayne W. Carter

# MM-600 HIGH-PERFORMANCE WAVEGUIDE SYSTEMS

The ultimate success of a microwave relay system depends on the high performance of every component. Since the MM-600 is a high-performance microwave system,[1] exceeding minimum CCIR requirements, the companion waveguide system described herein also must be of very high quality. Design targets were (at 2.0 Gc) an average reflection of about 2.5%; the waveguide systems are composed of straight rigid sections, straight twisted sections and rigid H- and E- plane bends. To suspend such waveguide systems and maintain performance under severe weather conditions posed a severe problem. Special design and production techniques were developed to obtain the required performance.

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The high-performance MM-600 waveguide system is designed to be compatible with an antenna considered very close to the state-of-the-art, and with the operating requirements of the MM-600 radio relay equipment.[1] In operation at 1.8 to 2.3 Gc under the severe environmental conditions of the Grande Prairie-Alaska system installation, no failure of any waveguide component has been reported to date. The performance specified for the waveguide system has been exceeded, contributing to the over-all success of the system.

### CURRENT MM-600 INSTALLATIONS

Radio relay systems based on this equipment have been installed in the Rimouski area[1] and in Alberta in Canada. The largest installation is from Grande Prairie in Alberta to Snag (Mount Dave) in the Yukon Territory near the Alaska border, 41 hops over a distance of more than 1200 miles. A contract has been awarded to RCA to install the Cento System using this type of equipment. This will connect Ankara, Turkey, and Karachi, Pakistan, using 90 hops to stretch about 3000 miles. Recently, a contract has been awarded to RCA Victor Company, Ltd., Montreal, to install a microwave radio-relay system linking Montreal and Vancouver.

### DESIGN GOALS

When development work on MM-600 equipment began, RCA Victor Company, Ltd., Montreal, was given the task of developing an antenna considered to be very close to the state-of-the-art. The transmission medium, however, remained somewhat in the background at that time. Most likely the fact that coaxial transmission lines and waveguides had been used in many forms obscured the problems inherent in designing such a medium to be compatible with a very-high-quality system.

Consequently, when the first system using MM-600 equipment was to be installed in the Rimouski area in Canada, a specification was written for such a conventional waveguide system; this specification was then submitted to a number of potential suppliers for equipment quotations. However, the performance required for proper operation of the system failed to be realized from existing waveguide components. Because of the advanced stage of the schedule, and of the desire to keep the cost under stringent control, RCA Victor Company, Ltd., decided to undertake the development of a waveguide system giving satisfactory performance. When the system was evaluated and performance calculated, the following design parameters were established:

1) Reflection of straight sections (less joint reflections), 20 ft. long = 0.5% maximum
2) Reflection of twisted section, 20 ft. long and with a rate of twist of 5° per linear foot (less joint reflection) = 0.5% maximum
3) Reflections of 90° E- or H-plane bends (less joint reflections) = 0.4% maximum
4) Reflection of joints connecting various components, joint maximum = 0.8% maximum
5) Reflection of flexible waveguide 10 ft. in length = 5% in straight position, maximum; 10% using maximum flexibility, maximum

The above list may appear to give a somewhat artificial separation of the reflections from various sources. From a practical point of view, it is not possible to measure the reflection of a 20-foot section of straight waveguide without including those reflections that originate at the joints. However, this approach has given reasonable results for synthesis and for evaluation of what performance could be expected.

### PRODUCTION ENGINEERING VS PERFORMANCE

The straight waveguide sections were made as aluminum extrusions, and all other waveguide components, except the flexible sections, were manufactured from these extrusions. Straight sections were made from one of the harder alloys. Flexible sections were purchased to conform with our specified requirements. The basic properties required for the straight waveguide sections (a smooth inside surface with no abrupt discontinuities) had to be maintained for all manufactured components. Actual dimensions of the cross-section were found to be less critical, and were allowed to vary 0.01 inch/inch. However, the cross-sectional dimensions at the ends were held to a tolerance of ±0.001 inch to eliminate excessive discontinuities at these locations.

Adherence to these rather tight tolerance limits was achieved by deliberately extruding the waveguide undersize and by sizing the end sections to nominal dimensions by driving in a long steel wedge. The surfaces of the steel block were polished and the block was hardened to facilitate this sizing operation which was carried out manually on a small hydraulic press. The taper of the sizing block was 0.005 inch/inch.

To further reduce the effect of reflections originating at the joints, the lengths of waveguide sections were "modulated", i.e., varied around certain standard lengths. This "modulation" is a function of the total length of each waveguide run and the number of joints required.

Twisted waveguide sections were produced from straight waveguide extrusions using the softer aluminum alloy 2S. Twisting was done by inserting a number of spaced rectangular plates on a central shaft into the waveguide section. These plates had small rollers on their sides to prevent damaging the internal surfaces. One end of the waveguide extrusion was then held firmly and the other rotated so that a permanent twist of 90° over a length of 18 feet resulted.

In this manner, a uniform rate of twist (within 1°/foot), was achieved which was adequate for the application. Twisted sections were made with both clockwise and counter-clockwise twist, and were cut to the length required to obtain the necessary rotation of the cross section.

To obtain the specified performance from right-angle waveguide bends, prime consideration was given to minimum bending radius. The inside radius for

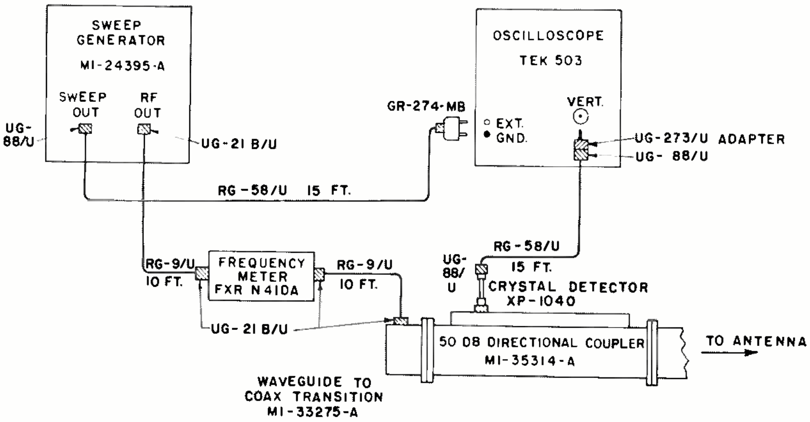

Fig. 1—Test setup for VSWR measurements, frequency sweeping.

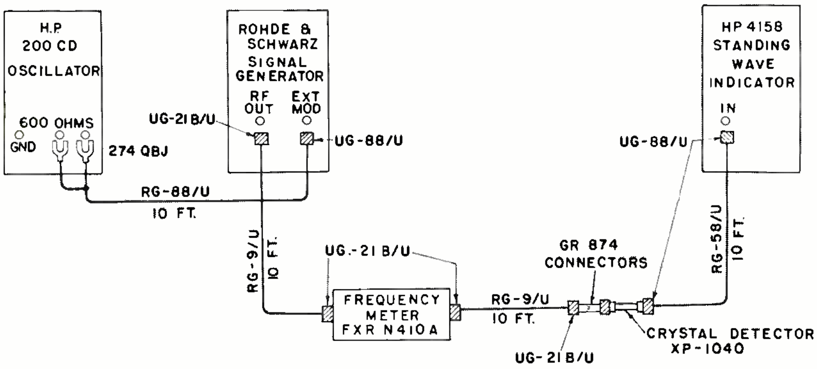

Fig. 2—Calibration setup for VSWR measurements, point-by-point method.

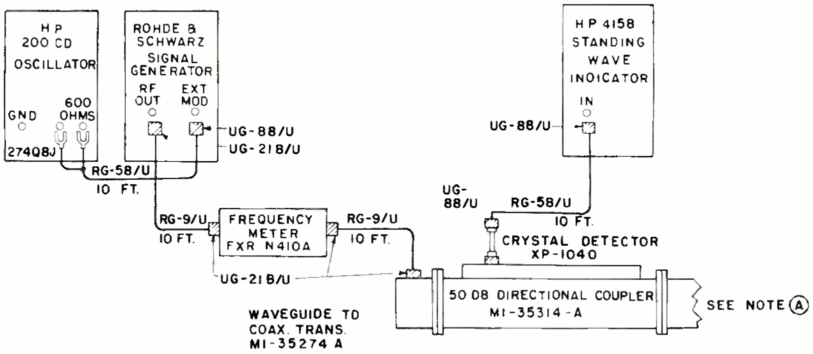

Fig. 3—Test setup for VSWR measurements, point-by-point method. NOTE A: 1) for waveguide assembly measurements, the coupler is connected to the horizontal waveguide; 2) for quadruplexer measurements, the coupler is connected to the quadruplexer, which in turn is connected to the equipment by four 10-foot cables.

both *H*- and *E*-plane bends was maintained at 17 inches and the arms of both types of bends were extended by straight sections of adequate length to permit sizing.

### VSWR MEASUREMENTS

As required in any engineering work with antennas and transmission lines, the reflection coefficients (VSWR) were carefully and accurately measured at specified frequencies. Fig. 1 shows how measurements were also made over the frequency band using a sweep generator; Fig. 2 shows the calibration setup; Fig. 3 shows the arrangements of test equipment to measure reflection coefficients at discrete frequencies and to display the reflection coefficient on an oscilloscope. The relationship between reflection coefficient Γ and the VSWR is:

$$\text{VSWR} = \frac{1+\Gamma}{1-\Gamma}$$

For example, for $\Gamma = 0.05 = 5\%$:

$$\text{VSWR} = \frac{1+0.05}{1-0.05} = \frac{1.05}{0.95} = 1.10$$

A significant piece of equipment for measuring such low reflection coefficients is the 50-db directional coupler developed for this purpose. This coupler has a directivity of 44 to 46 db, giving a limit of 0.5% to 0.7% to the reflection coefficient that may be measured with accuracy. Tables I to IV show results of reflection coefficient measurement for the following cases: Table I, Rigid Waveguide; Table II, Twisted Waveguide; Table III, 90° Waveguide Bends and Table IV, Installed Waveguide System.

Fig. 4 shows the reflection coefficient limit in percent as a function of length for a complete assembly. This curve is based on the parameters given above for the waveguide components and on the use of "modulation" of waveguide section lengths.

### ELECTRICAL-MECHANICAL DESIGN CONSIDERATIONS

Although the design and manufacture of the components are important first steps in the total engineering and application of a waveguide system, the components must be installed and tested under adverse weather conditions before adequate performance can be assured. To achieve this goal, several types of hardware are required to suspend and carry the waveguide along the tower and into the building where radio equipment is located. The design of such hardware is based on two requirements: one is the ability of the hardware to align the antenna in both the horizontal and vertical planes; and the other is that the hardware be strong enough to withstand the mechanical loading imposed on the waveguide and its suspension by wind, ice, and temperature.

Because of the high performance required of the antenna-waveguide system, flexible waveguide sections could not be installed between the antenna and the rigid waveguide. The waveguide suspension was designed so that the waveguide rotated around the same vertical axis as the antenna. Vertical alignment of the antenna introduced some deformation and stress into the rigid 90° bend connecting the antenna to the waveguide. Because the vertical deviation of the antenna from the horizontal was limited to very small angles, such deformations and stresses were easily tolerated.

The mechanical loading imposed on the waveguide and its suspension had three sources: wind, ice, and temperature. The wind loading was transferred to the tower by horizontal support assemblies spaced at 10-foot intervals. Although ice coatings of up to 12 inches in thickness had to be accommodated in special cases, the general design was for 2 inches. This 2-inch ice coating increased the dead load of the waveguide from about 4 pounds per linear foot to approximately 20 pounds. The waveguide run was supported from the top, close to the antenna, with spring-type vertical supports placed in adequate number along the tower height. In those cases where the strength of the waveguide joints required additional support, extra spring mounts were provided. Because of the higher thermal coefficient of expansion of aluminum relative to steel, the waveguide suspension was designed to allow vertical movement of the waveguide relative to the tower in spite of ice coatings. Because the movement of the bottom end of the waveguide at low temperatures (i.e., when coated with ice), was upward (toward the antenna) all spring hangers had to be preloaded, subjecting the waveguide to a compression stress, expecially at higher temperatures during the summer season.

Fig. 4—Curve showing the maximum (VSWR) reflection coefficient versus the waveguide line lengths.

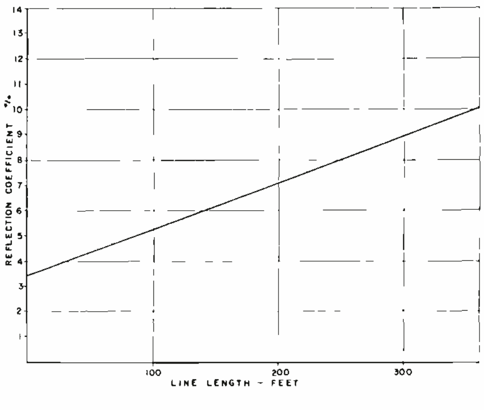

**TABLE I—Results of Measurements on Straight Waveguide, 10 Sections 20-ft. Long, Each Connected in Tandem**

| *f, Mc* | *No. 1*<br>*T, env (%)* | *f, Mc* | *No. 2*<br>*T, env (%)* |
|---|---|---|---|
| 1840 | 1.59 | 1845 | 3.05 |
| 1880 | 2.45 | 1860 | 2.75 |
| 1940 | 2.54 | 1910 | 2.25 |
| 1955 | 2.47 | 2000 | 3.25 |
| 2020 | 3.00 | 2015 | 3.30 |
| 2085 | 3.02 | 2070 | 3.10 |
| 2125 | 1.95 | 2110 | 2.70 |
| 2160 | 3.27 | 2165 | 3.27 |
| 2220 | 2.90 | 2220 | 3.15 |
| 2290 | 3.04 | 2260 | 3.93 |
| *T env (%)* | 2.62 | | 2.62 |
| *T max (%)* | 3.27 | | 3.93 |

*T env* (%) is a measure of the maximum reflection within 50 Mc intervals in percent.

*T env* (%) is the average value of the envelope of the reflection in percent.

*T max* (%) gives the absolute maximum reflection coefficient in percent.

**TABLE II**

**Results Measured on Two Clockwise and Two Counterclockwise Twisted Waveguide Sections Connected With One Straight Section, Giving a Total of Five Sections Connected in Series**

| *f, Mc* | *T, env (%)* |
|---|---|
| 1840 | 2.90 |
| 1850 | 3.35 |
| 1900 | 3.30 |
| 1950 | 2.90 |
| 2010 | 2.90 |
| 2055 | 2.30 |
| 2130 | 2.95 |
| 2160 | 2.55 |
| 2220 | 2.45 |
| 2255 | 2.25 |
| *T env (%)* | 2.78 |
| *T max (%)* | 3.35 |

**TABLE III—Results Measured on 90° Waveguide Bends**

| *f in Mc* | *H-Plane Bends* | | *E-Plane Bends* | |
|---|---|---|---|---|
| 1800 | 1.88 | 3.89 | 1.88 | 3.96 |
| 1850 | .64 | 1.93 | .61 | 3.25 |
| 1900 | 1.58 | 2.64 | 2.10 | 2.79 |
| 1950 | .94 | .41 | 1.31 | .88 |
| 2000 | 1.91 | 1.21 | 1.33 | .39 |
| 2050 | 54 | 1.63 | 1.12 | .25 |
| 2100 | .90 | 1.16 | 1.05 | 1.87 |
| 2150 | .47 | 1.70 | 1.85 | 2.26 |
| 2200 | .60 | .50 | 1.76 | .49 |
| 2550 | .89 | .71 | .86 | .58 |
| 2300 | .51 | 1.38 | .73 | 1.27 |

The values in this Table give the reflection coefficient in percent at the particular frequencies: the first two columns represent *H*-plane bends and the last two *E*-plane bends.

**TABLE IV—Measurements Taken in the Field of Two Installed Systems**

System A:
327′– 2″ vertical waveguide run
10′– 0″ flexible waveguide section
13′–11″ horizontal waveguide run

| *Peak Reflections* | | *Reflections at Operating Frequencies* | |
|---|---|---|---|
| *f* | Γ (%) | *f* | Γ (%) |
| 1723.5 | 4.6 | 1864.0 | 3.9 |
| 1830.5 | 6.9 | 1980.0 | 4.5 |
| 1943.0 | 6.0 | 2149.5 | 2.0 |
| 2023.5 | 8.3 | 2265.5 | 4.3 |
| 2155.0 | 9.4 | | |
| 2218.0 | 9.6 | | |
| 2293.5 | 5.9 | | |

System B:
216′– 5″ vertical waveguide run
10′– 0″ flexible waveguide section
13′–11″ horizontal waveguide run

| *Peak Reflections* | | *Reflections at Operating Frequencies* | |
|---|---|---|---|
| *f* | Γ (%) | *f* | Γ (%) |
| 1713.5 | 3.1 | | |
| 1795.0 | 6.0 | 1864.0 | 2.3 |
| 1973.0 | 6.3 | 1980.0 | 3.7 |
| 2050.0 | 5.3 | 2149.5 | 2.5 |
| 2107.0 | 4.4 | 2265.5 | 1.9 |
| 2194.0 | 5.8 | | |
| 2275.0 | 4.0 | | |

## ACKNOWLEDGMENT

The complete waveguide system was developed within the Antenna Group of RCA Victor, Ltd., Montreal. In particular, P. Foldes and N. Gothard carried out electrical design. T. Szirtes designed the suspension system and U. O. Cunard determined production methods and procedures.

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# MILLIMETER WAVES
## . . . Present and Future

Peculiar characteristics distinguishing behaviour of millimeter waves from other frequencies, the present status of development in the millimeter wave field, and potential applications of millimeter waves in aerospace communications and plasma research are discussed in this paper. The results and implications of experimental work now in progress in the RCA Victor Research Laboratories in Montreal are summarized.

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ONE OF THE active areas of investigation in modern electronics is the study of millimeter waves. These very short wavelengths, by definition between 1 cm and 1 mm, are of interest not only because of their potential applications in special communication systems, but because of their value in the study of molecular structure and in the investigation of plasmas. Of philosophical interest, also, is the fact that this wavelength range represents the formal closing of the gap between radio waves and infrared waves, which extend, according to some definitions, to a wavelength of 1000 microns (or 1 mm). The distinction is, of course, purely arbitrary, and the last foundation for it is rapidly disappearing with the ability to generate coherent radiation in the infrared and optical regions.

### SOME HISTORY

Before turning to the present situation in millimeter waves, let us look briefly at the past. Surprisingly enough, the history of observation of electromagnetic radiation having millimeter wavelengths goes back more than sixty years. Before 1900, Bose[1] had carried out many experiments at wavelengths down to 5 mm, generated by spark discharges, and many other experimenters worked at wavelengths near the millimeter range. Crude versions of many devices used in modern microwave practice — waveguides, pyramidal horns, parabolic reflectors, and spectrometers—were used. Much of the work drew its inspiration from the corresponding optical techniques. To a large extent, these concepts were overlooked in the subsequent development of the longer wavelengths for practical use and have only been revived in the past twenty years.

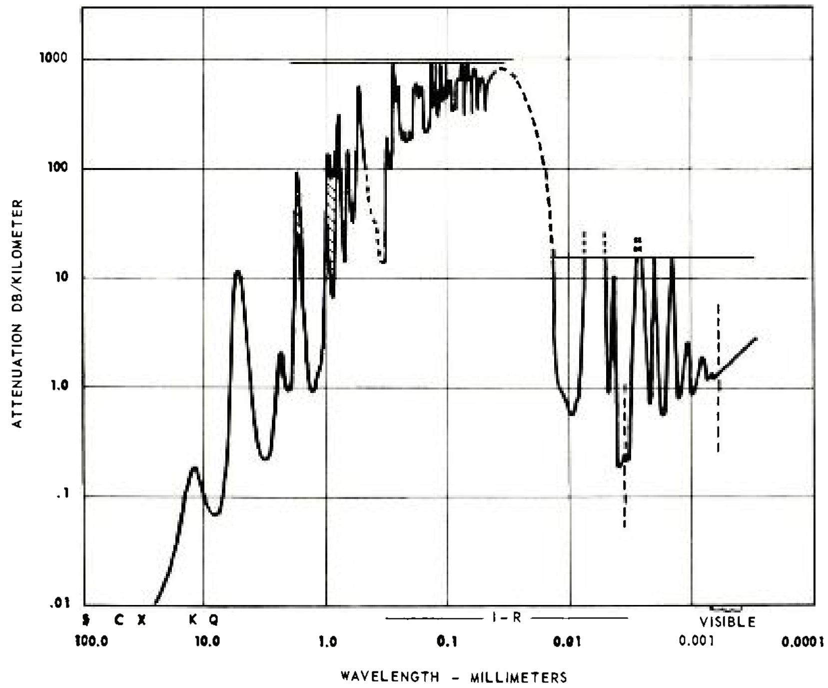


Fig. 1—Variation of attenuation with wavelength (compiled from a number of sources). Shaded areas represent conflicting information from two sources. Horizontal lines indicate upper limit of accurate calculation of attenuation from transmission data quoted. Vertical broken lines indicate range with varying atmospheric conditions. Broken curve indicates uncertainty of measurement or no measurement.

Since those early experimental days, interest in radio waves for practical purposes has shifted to the use of frequencies at which signals can be generated and manipulated coherently. Until recently, this has meant frequencies which can be generated by more or less conventional electron tubes. The result of this has been a slow progression from relatively low frequencies in the early days of broadcasting, through ever-increasing frequencies to the present use of the longer millimeter wavelengths in experimental communication systems, and the capability of generating coherent radiation at frequencies into the submillimeter-wavelength range. The recent development of maser techniques has also made possible the generation of coherent energy at particular frequencies, determined by the energy level structure of the particular systems used. Maser oscillators have been operated at specific frequencies in the millimeter-wave region and in the infrared and optical, as well as at longer wavelengths.

The progress in the use of higher frequencies, limited chiefly by the ability to generate useful amounts of coherent power, has been by no means steady, but has proceeded in spurts. The greatest of these occurred during World War II, under the impetus of radar. This brought development to the brink of the millimeter wave range. For some time, 9 mm remained the shortest wavelength at which practical investigations could be carried out. Sources of power at 9 mm were commercially available shortly after the war and a number of antennas and experimental systems were developed at 9 mm around 1950, including a parallel-plate Luneberg lens scanning antenna developed by the forerunner of the RCA Victor Research Laboratories in Montreal. Because of the increasing atmospheric attenuation (Fig. 1), which made radar and communications applications of higher frequencies seem unattractive, there seemed little incentive to engineering developments at higher frequencies. Even at 9 mm, in the trough between the water-vapor absorption band at 12 mm and the oxygen absorption at 5 mm, atmospheric attenuation was high enough to limit radar and communication applications to relatively short ranges. The increased activity in millimeter-wave generation in the past few years has resulted in the availability of power sources at 2 mm and in experimental tubes operating well into the submillimeter regions. This activity is due in part to the opening up of new potential uses for these frequencies in plasma investigations and in extra-atmospheric communications.

### MILLIMETER-WAVE CHARACTERISTICS

The source of the most striking difference in behaviour between millimeter waves and radiation of longer wavelengths is that many of the quantum-energy jumps corresponding to transitions between molecular rotational energy levels in a large number of substances correspond to frequencies in the millimeter-wave range. In such cases, if the molecule possesses a magnetic or electric moment which will permit its interaction with electromagnetic radiation, then it may absorb a quantum of incident radiation at one of these frequencies to increase its energy level. Of particular interest is the strong absorption at some frequencies shown by a number of constituents of the Earth's atmosphere (e.g. oxygen and water vapor) as well as by gases known to be constituents of the atmospheres of other planets (e.g. ammonia). The lowest frequency at which a significant absorption band in the Earth's atmosphere is encountered is at a frequency just below the millimeter-wave range — in K-band, this being the well-known vater-vapor absorption band; but it is in the millimeter-wave range that the attenuation due to absorption becomes really serious. Fig. 1 shows the variation of atmospheric attenuation with wavelength for humid air at sea level across the whole spectrum from radio waves to visible light based on data extracted from a number of sources.

This strong atmospheric attenuation makes the use of millimeter-wave radiation unattractive for communication or radar purposes at sea level, except perhaps over very short ranges. At high altitudes however, where the atmospheric pressure is low, the attenuation becomes negligible except exactly at the absorption peaks which at low pressures become very sharp resonances. Some of the broad absorption bands observed at sea level are resolved into many of these very sharp absorption lines at low pressure. This is shown for the 5-mm oxygen absorption in Fig. 2. One suggested application of this phenomenon is communication between high-flying aircraft secure from detection from the ground by operating at a frequency between two of these narrow absorption lines. Another incidental effect of the absorption of millimeter waves by the atmosphere is to make the atmosphere a source of thermal noise at these frequencies, so that the effective antenna noise temperature for a ground-based antenna will approximate the actual temperature of the atmosphere at frequencies where atmospheric absorption is high, even though the antenna be directed toward cold regions of the sky. Another source of attenuation in the atmosphere which becomes serious in the millimeter-wave region is the absorption. and to some extent scattering, due to rain and fog. The effects of rain, and even heavy fog, are seen also in the centimeter-wavelength range, although generally to a lesser degree—the attenuation decreasing rapidly with increasing wavelength.

There is also a useful side to the phenomenon of absorption. The exact values of the frequencies at which absorption occurs in the gases at low pressure are dependent on the details of the structure of the molecules and so offer valuable clues in the investigation of this structure. The molecule structure of hundreds of substances has been investigated by microwave absorption spectroscopy adding to the knowledge which can be gained from the study of infrared absorption spectra.

### INTERACTIONS WITH PLASMAS

The interactions of millimeter waves with highly ionized gases, or plasmas[2], are also of interest. A plasma is characterized by its electron density and by a quantity known as the collision frequency, which is roughly the frequency of collision of electrons with larger particles in the plasma. Corresponding to the electron density is a frequency, the so-called *plasma frequency*. Below this frequency, the plasma reflects electromagnetic radiation. Near the plasma frequency it absorbs energy, and above this frequency it acts as a lossy dielectric, of dielectric constant less than unity. The losses depend in a complicated manner on the value of the collision frequency. At frequencies far above the plasma frequency, the dielectric constant approaches unity and the losses approach zero.

The maximum electron density in the ionosphere of about $10^6$/cm$^3$ corresponds to a plasma frequency of 9 Mc (33 meters). It takes a very-high-electron-density plasma of $10^{13}$/cm$^3$ to give a plasma frequency corresponding to a 10-mm wavelength, and an even higher electron density of $10^{15}$/cm$^3$ for 1 mm.

Since millimeter waves can penetrate very dense plasmas, two practical applications appear. The more obvious is the potential use of millimeter waves in communication from space vehicles during the plasma-surrounded condition induced by re-entry, which causes the communication blackout familiar to all who have followed the recent Project MERCURY tests (in which lower frequencies incapable of penetrating the plasma sheaths were used, of necessity). Another equally important, though less spectacular, use of the ability of millimeter waves to penetrate high-density

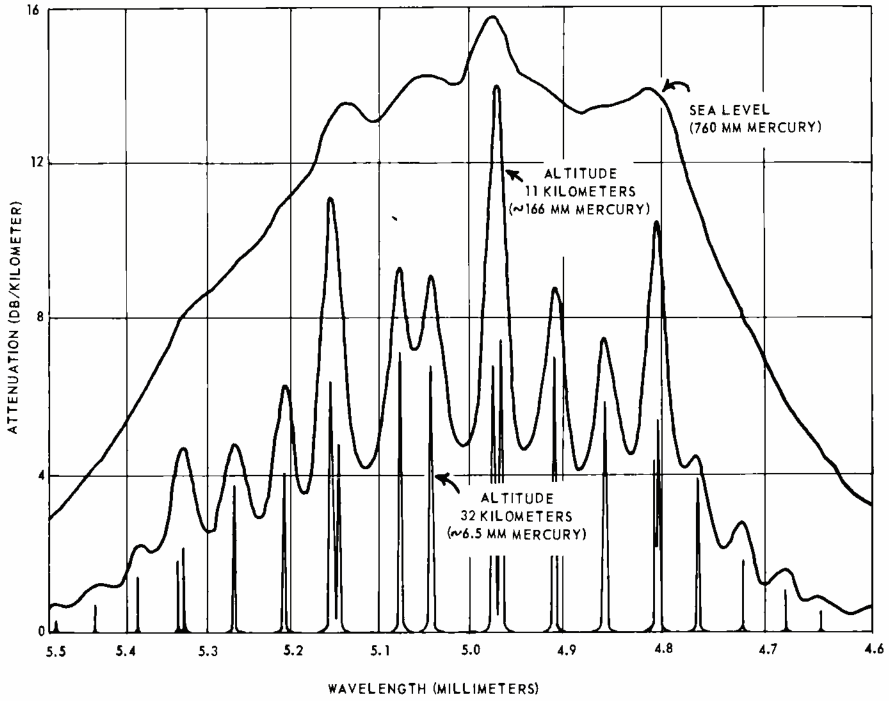


Fig. 2—Variation of attenuation with wavelength at various altitudes in the region of the 5-mm oxygen absorption band. (Adopted from data given by T. F. Rogers). Note the very low attenuation observed between the sharp absorption lines at high altitudes.

plasmas is in the study of conditions inside laboratory plasmas. This constitutes a valuable tool in thermonuclear research and other fields depending on plasma technology.

### APPLICATION TRENDS

The main problem in the application of millimeter waves is still the means of generating adequate power at these frequencies. Progress in the last fifteen years has not been spectacular, except for some developments in the past few years. Klystrons are still the most common laboratory generators and are now available commercially at 2-mm wavelengths. Backward-wave devices have been developed as generators through almost all of the radio spectrum, and such devices have on a developmental basis produced several milliwatts at 0.7 mm. Much study has been devoted to special electronic techniques for the generation of power at very short wavelengths, including Cerenkov radiation, radiation emitted by a charge moving in or near a medium at a velocity greater than the velocity of electromagnetic radiation in that medium, and other techniques of megavolt electronics. One of the simplest and cheapest sources of 2-mm radiation, however, remains the harmonic generator crystal working from a 4-mm klystron source.

The problem of components for use in the millimeter range is not so difficult, at least in so far as the linear circuit elements are concerned. While sizes and tolerances do become small enough at the shorter millimeter wavelengths to make manufacture not at all a simple matter, all the usual waveguide components are commercially available at wavelengths down to 2 mm. Although few, if any, 1-mm components are commercially available, there is little doubt that they could be built using appropriate care. Reasonably efficient video detectors are also available down to 2 mm and have been made to 1 mm. Nonreciprocal components and other ferrite devices have not been carried so far, but there is little reason to believe they will not be in the near future.

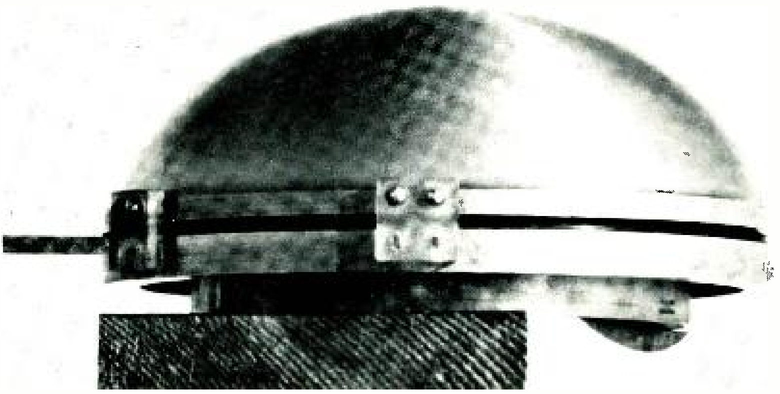


Fig. 3—A parallel plate luneberg lens antenna for 9-mm wavelength. This was designed and built at RCA Victor in Montreal in 1950.

Partly because of the difficulties of construction of the standard components for rectangular waveguide, but even more because of the high attenuation in the very-small-cross-section rectangular guide and components, there has been considerable interest in other types of low-attenuation guide, circular guide propagating $TE_{01}$ mode, surface lines, dielectric guides of various types, and $H$-guide. Components for most of these do not yet exist, and even the problems of maintaining mode purity in practical transmission systems have not been completely solved. One promising technique is the use of lens-and-mirror systems in quasi-optical methods of transmission. Several interesting types of components based on the properties of prisms, wire grids, and perforated plates have been built to duplicate the functions of standard waveguide components in these quasi-optical transmission systems.

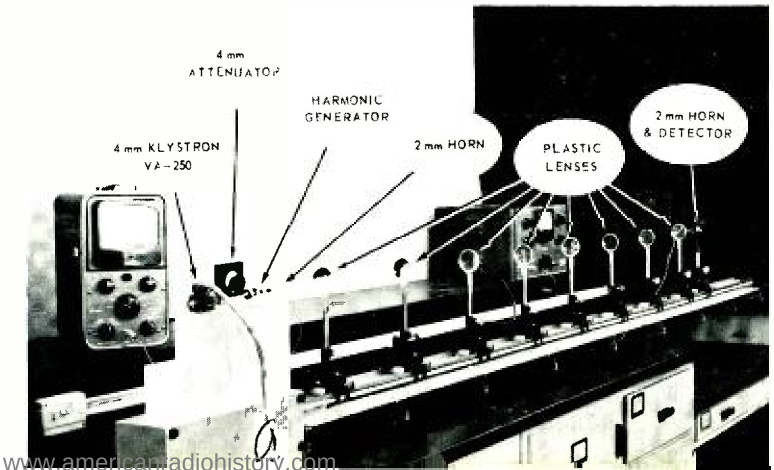
Many ideas and devices which have first been developed for use at optical and infrared frequencies are now finding application at millimeter wavelengths. The thermal detectors, the bolometer and the more sensitive Golay cell, are in principle, not dependent on frequency; with appropriate modifications, they can be used at millimeter-wave frequencies. Recently, another type of detector—the semiconductor detector using photoconductive or similar effects based on quantum mechanical principles—has shown promise of extension to millimeter wavelengths using special materials (e.g. indium antimonide). These semiconductor detectors, at least in their present form, require to be operated at extremely low temperatures, reached by using liquid helium at reduced pressures.

### WORK IN THE MONTREAL LABORATORIES

The RCA Victor Research Laboratories in Montreal, since their formal establishment in 1955, have worked continuously in the millimeter or near-millimeter region, using these frequencies chiefly as research tools in investigations of propagation phenomena, both in the normal atmosphere and in plasmas. Before this, work at 9 mm had been carried on since 1949, by their predecessor, the Research Group of the Engineering Department. Fig. 3 shows a 9-mm parallel-plate Luneberg lens developed by this group in 1950. In 1959, the Research Laboratories undertook a survey of the state of the art in millimeter and near-millimeter waves under the sponsorship of the Defence Research Board of Canada and the Royal Canadian Air Force[3]. In early 1961, a contract was received from the United States Air Force to conduct a more extensive survey with emphasis on the application of this spectral region in aerospace communications and with experimental work to follow based on the findings of the survey. This work was on behalf of the Electromagnetic Warfare and Communications Laboratory of the Air Force Systems Command. The results of the survey are now being published in a seven-volume report[4], and experimental work is in progress in four areas suggested by the survey.

One of these investigations is a study of beam transmission techniques and of

Fig. 4—A beam transmission system for 2-mm radiation. (This mode of transmission has been discussed by Goubau and Schwering, IRE Trans. AP-9, 248, 1961). This is being used for studies of this mode of transmission and investigations of quasi-optical techniques for performing circuit operations with millimeter waves.



components for use in beam-transmission systems. Fig. 4 is a system established for preliminary experiments using ordinary plastic lenses, originally sold as cheap optical magnifying lenses. Even with this system, despite reflection losses and the fact that the lenses are not made of a special low loss material, considerably lower losses are observed at 2 mm than with conventional rectangular waveguide. A system using dielectric material of lower loss and of lower dielectric constant for lower reflections is being constructed, as are a number of components for performing various standard microwave operations using quasi-optical techniques at 2 mm.

Another experiment in progress concerns the application of strongly cooled indium antimonide as a detector of electromagnetic radiation at millimeter wavelengths. In this experiment, also in its early stages, a slice of the semiconductor is cooled to liquid-helium temperatures (4.2°K, and in later experiments perhaps lower by reducing the pressure over the liquid helium) and the variation of resistance with irradiation at 2 mm and at 4 mm under various experimental conditions is observed.

Theoretical studies are also under way to clarify the mechanism of the resistance variation.

The two other experimental programs are concerned with the interactions of millimeter waves and plasmas. One is an extension to shorter wavelengths of previous investigations of the effect of a slab of plasma on the radiation from a horn antenna. Observations are being made of the phase and amplitude of both the reflected signal and the transmitted signal at various angles in the radiation pattern. An ingenious technique provides what is essentially a Smith diagram plot for varying plasma density. The remaining program is obtaining similar measurements on a plasma confined within a waveguide structure, for the purpose of investigating the possibility of constructing microwave components utilizing the properties of plasmas. This latter experimental program is supported by a theoretical study to establish suitable theory for this confined plasma.

## THE FUTURE

Looking ahead to the future, there is little doubt that one major application of millimeter waves will continue to be in the laboratory, as a tool in unraveling the secrets of nature. The use of millimeter waves in the study of molecular structure is already well established, and new ways of using these frequencies in elucidating the structure of matter at all levels may appear as engineering developments provide greater powers and more sensitive detectors. Certainly, the continuing use in plasma diagnostics is assured.

The other major use will probably be communications in outer space. Ground based or low altitude uses in communications or radar will be confined to very-short-range, specialized applications, or to those in which transmission can be through pipes which can be evacuated or filled with non-absorbing gases. It is at very high altitudes or in space that a whole new field of use for these wavelengths may be expected to open up. Free from atmospheric absorption and random fluctuations in direction of arrival, advantage can be taken of the very high gains obtainable from moderate antenna sizes at millimeter wave frequencies. This makes possible communication over very large distances using relatively low powers, as long as the antennas can be pointed toward each other and maintained sufficiently accurately. From this standpoint, 10 mw at 3-mm wavelength *is as useful as* 10 kw at 3 meters. It has been estimated[5] that powers in excess of 100 watts may be available at 1 mm by 1966. The operation and maintenance of such power sources in a satellite may pose additional problems.

In this brief review of a field in which a great deal of work has been done, especially in the last few years, it has been impossible to do more than mention many areas about each of which volumes could be, and have been, written. The reader who is interested in pursuing the subject further is referred to the *Bibliography* given below, and in particular to the RCA Victor Research Laboratory Reports.[3,4] The results of experimental work in progress at the time of writing under the USAF contract referred to above will be described in reports which will be available in September 1962.

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# SOME CURRENT MICROWAVE RESEARCH AT RCA LABORATORIES

This paper describes a part of the work being done in the Microwave Research Laboratory, RCA Laboratories, Princeton. Several devices and fields of investigation are discussed as being representative of the main purpose of this Laboratory—to devise new means of generating greater power and of amplifying with less noise, at increasingly higher frequencies. The particular examples are drawn from three broad areas of research: solid-state devices, electron beam tubes, and plasmas.

**DR. STANLEY BLOOM** received his BS in Physics from Rutgers University in 1948, and PhD in Physics in 1952 from Yale University, where he worked on gaseous electronics and on the theory of spectral line broadening. He joined RCA Laboratories in 1952, where he has worked on traveling-wave tubes, beam electronics, molecular amplification, plasmas and parametric amplifiers. He is at present in charge of a group doing research on microwave tubes in the Microwave Research Laboratory of RCA Laboratories. Dr. Bloom has received two RCA Achievement Awards for his work on the noise properties of traveling-wave tubes. He is a Senior Member of the IRE and a member of the American Physical Society, Sigma Xi, and Phi Beta Kappa.

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BECAUSE THERE IS much overlap in the research to be described herein on solid-state devices, electron beam tubes, and plasmas, the division of this paper into these categories is somewhat arbitrary. For example, both solid-state devices and beam tubes are used as low-noise amplifiers; solids, tubes, and plasmas are all in the race to reach the millimeter wavelength region of the microwave spectrum; some of the plasma work deals with electron-hole plasmas in solids and some with electron beams shot into a plasma; some of the cathode work has application to low noise tubes, to plasma synthesis and to high power tubes—and so forth.

No mention will be made of masers or lasers. These quantum electronic devices go a long way toward answering the needs set forth in the abstract, above; however, they lie in another bailiwick and much information is available in the literature about them. Nor is there room here to discuss any of the other work in other Laboratories at Princeton that relate to microwaves. For example, thin-film and tunnel-effect studies, photoemission, ferroelectricity, superconductivity, acoustic waves and cyclotron resonance in solids, are all given short shrift even though it is such studies that lead to tomorrow's microwave devices.

## SOLID-STATE MICROWAVE DEVICES

The field of solid-state microwave *active* devices is relatively new. Its impetus came from the discovery of low-noise microwave amplification via parametric diodes, and from the later discovery of intrinsic negative resistance in the tunnel diode. Much of the pioneering work on these two devices was done at RCA Laboratories. Today, the main emphasis is on solving certain difficult circuit problems, on extending the amplifiers to higher frequencies, and on realizing efficient solid-state millimeter-wave generators.

Although tunnel-diode amplifiers have been around now for several years and progressively lower noise factors have resulted from improvements in materials and fabrication, these devices have not yet taken their promised place in practical systems. The reason is that they suffer from a drawback indigenous to negative-resistance devices—*instability.* These are two-terminal affairs, and so variations in load and input impedances affect their gain. The noise factor also suffers from reflections from the load. Although a long-recognized solution to this problem has been to use nonreciprocal elements to isolate the amplifier from its terminations, little had been done in way of realization. To this end, studies are underway at this Laboratory on a ***traveling-wave tunnel-diode amplifier*** using an L-band coaxial transmission line containing a distributed ferrite isolator.[1]

The amplifier (Fig. 1a) is in its early stages and does not yet incorporate the ideal situation wherein the nonreciprocal material is integrated with a distributed negative resistance. The four to six germanium tunnel diodes (obtained from RCA Semiconductor & Materials Division, Somerville) are part of the inner conductor, the separation between diodes being small compared to a wavelength. The ferrite cylinder provides 15-db reverse loss and only a few tenths of a db forward loss. Measurements, made at L-band for convenience, show the device to have a 15-db net gain. The bandwidth is 5 to 10 percent, which is less than the bandwidth of the ferromagnetic resonance and so leaves room for further improvement. Both open- and short-circuit stability have been achieved. The noise factor, yet to be measured, is due to shot-noise current and so is proportional to the DC current and to the magnitude of the negative resistance. This speaks for getting better materials, perhaps gallium antimonide. Such diodes, in non-traveling-wave amplifiers, have given 2.5-to-3.0-db noise factors. In the traveling-wave version, the noise factors should be no worse and may well be better, since the ratio of negative resistance to input resistance, per unit length—which determines the noise factor — can be low, with the resulting small gain per unit length being made up by use of a longer structure. With stability, which has been achieved, and with noise factors in the 2.5-to-3.0-db range (which appear likely) this DC "pumped" solid-state amplifier would be competitive with traveling-wave tubes in their common range of frequencies.

About two years ago, work in this Laboratory resulted in a tunnel-diode down converter with unique properties.[2]

This device was stable, had low noise factors, and exhibited conversion gain rather than loss. The gain resulted from the usual negative-resistance portion of the diode's *I-V* curve, the mixing resulted from the nonlinear portion of the *I-V* curve near the peak-current point, and the low noise factor was due to the exclusion of IF noise by virtue of the conversion gain. Subsequent experiments showed that noise factors as low as 2 to 3 db could be achieved when the local oscillator signal was strong enough. This work was done at UHF; its success stimulated the attempts now in progress to realize a ***millimeter-wave tunnel-diode down converter.***[3] The hope is that this converter, in contrast to present millimeter-wave detectors, will have a low noise factor.

This work is proceeding in two stages. First, tunnel diodes—in this case gallium antimonide with zinc dots—are being checked for their nonlinearities by being operated as detectors in the positive-slope region of the *I-V* curve (Fig. 1b). The nonlinearity in this region is greater than that obtainable from a conventional crystal diode; also, the losses are an order of magnitude less than in a conventional diode because the tunnel diode is heavily doped. A 1-kc modulation on a 55-Gc carrier was detected with a sensitivity 15 db greater than is obtainable at that frequency with a conventional 1N53 crystal diode. This is in agreement with calculation. The second stage of this study will be an investigation of the possibility of conversion with gain. In this case, the diode will still be biased in the positive slope part of the *I-V* curve, but the local-oscillator RF voltage will be strong enough to cause the total voltage to swing over into the negative-resistance part of the curve during part of the cycle.

During the course of this work, it was found that the tunnel diode at ultra-microwave frequencies exhibits nonlinear capacitor effects. In other words, at high enough frequencies the tunnel diode is mainly reactive and its parametric, or varactor, aspects became important. Furthermore, because the diode is heavily doped its series resistance is low. Thus, the tunnel diode, when acting as a varactor diode, offers promise of being useful for efficient harmonic generation of millimeter-wave power. Preliminary calculations indicate that generation of 1.2-mm waves as a fourth harmonic may be possible with as much as 10-percent efficiency.

### ELECTRON BEAM TUBES

Work on electron beam tubes represents a large fraction of the total effort in the Microwave Research Laboratory. This may seem somewhat contradictory in view of the fiat stated in the abstract which calls for "new" devices. The traveling-wave tube goes back to the late 1940's and is itself an off-shoot of the klystron, which predates it by another ten years.

Yet both these tubes, in one or more of their many forms, are still being researched. There are many reasons: Traveling-wave-tube amplifiers today offer a hard-to-beat combination of enormous bandwidth, high and stable gain, and ultra-low noise factors. There are cogent reasons for believing that further research will lead to further noise reduction. Also, the traveling-wave principle itself—i.e., the interaction mechanism resulting from the coupling between a beam and a circuit traveling-wave—has led to a bewildering array of beam-type devices whose capabilities have not yet been fully explored. Furthermore, the millimeter- and submillimeter-wave portion of the spectrum is a constant challenge; although beam tubes are certainly not easy to build at ultra-microwave frequencies, the fact remains that a beam tube—the backward-wave oscillator, a variant of the TWT—has so far made the most successful breach of the millimeter-wave barrier. There is still room for innovations, in terms of new types of circuits and new coupling schemes. Finally, beam tubes are interesting because electron beams are interesting. Beams exhibit many disconcerting phenomena when run under conditions that are closer to the real world than to the simplified models of the theorist. As a case in point, a new wave-damping effect occurring on beams that are "hotter" than usual has recently been observed and explained in this Laboratory. This damping effect has important consequences, not only for low-noise tubes and power tubes, but also for plasma devices.

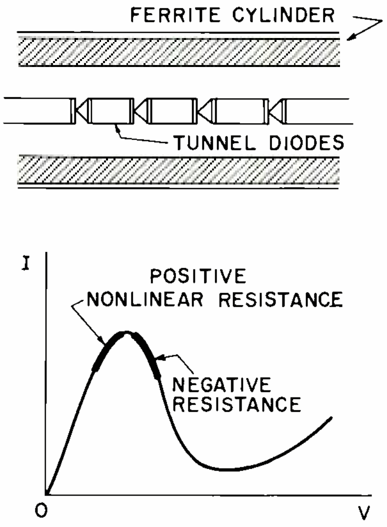
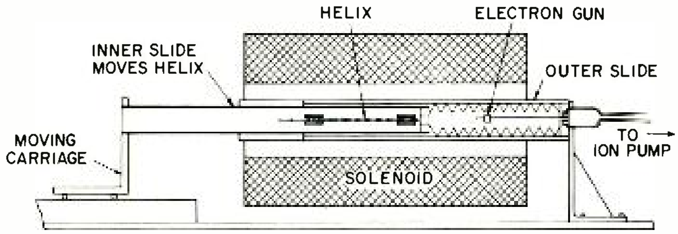


Fig. 1—(a) Traveling-wave tunnel diode amplifier uses diodes along the inner conductor of a coaxial transmission line, and uses a ferrite cylinder to achieve isolation. (b) The current-voltage characteristic of a tunnel diode has a region of positive nonlinear resistance useful for mixing, and a region of negative resistance for amplification.

It was mentioned that today's traveling-wave tubes give excellent noise factors. This is true. However, it is not fully known why they are so good and whether or how they can be made still better. The noise factor of the TWT is determined by noise processes occurring in the beam very close to the cathode. An electron beam, like any noisy four-pole, contains two noise sources: a noise-current source due to shot noise, and a noise-voltage source due to thermal energy. In the jargon of the field, $S$ measures the magnitude of these two sources, and $\pi$ measures their mutual correlation. The tube noise factor $F$ is proportional to the difference $S$-$\pi$; hence, one wants to design a gun which minimizes $S$ and maximizes $\pi$. Also, one would like to know how $S$ and $\pi$ vary as one changes the beam geometry, current density distribution, and beam voltage near the cathode. Because the cathode region is difficult to probe directly, its properties must be inferred. To this purpose a research tool, known locally as the ***SπF apparatus,*** was conceived and developed[4] at this Laboratory and is being used to measure $S$ and $\pi$ values for various low-noise TWT guns. The apparatus (Fig. 2) is essentially a TWT with adjustable cathode-to-helix separation. Values of $S$ and $\pi$ are inferred from measurements of the minimum and maximum noise factors that result when the helix position is varied. The technique differs from others in that it uses an electronically simple apparatus in which excellent vacuum conditions can be maintained. As a consequence, this is the first instrument of its type which has yielded $S$, $\pi$ data on guns giving ultra-low noise factors. The measurements show that although the lowest noise factors occur when the gun-electrode voltages are such as to minimize $S$, the correlation $\pi$ is essentially unchanged by this optimization. If follow-up measurements now in progress bear out the preliminary findings, serious doubts may be raised about the sacrosanct linearized theories of noise in the multivelocity region near the cathode.

It was mentioned that the noise factor of a traveling-wave tube—or, for that matter, of any beam-type amplifier—is



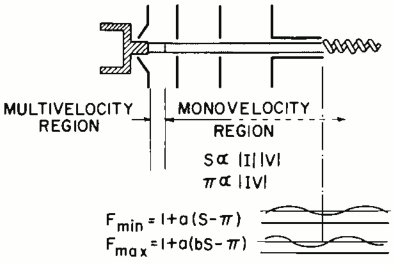


Fig. 2—The gun-to-helix separation in the "*SπF apparatus*" is adjustable by means of bellows. By varying this separation and measuring the resulting minimum and maximum noise factor of this traveling-wave tube, one can solve the theoretical equations to obtain the important noise parameters $S$ and $\pi$; the constants $a$ and $b$ are fixed by the parameters of the tube and are known.

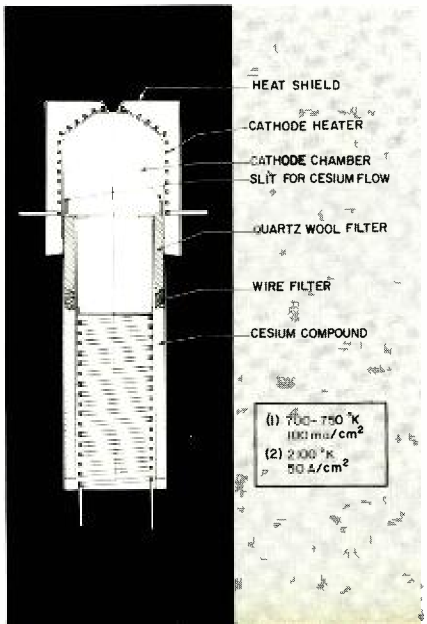
proportional to $S$-$\pi$. The constant of proportionality contains the cathode temperature as a factor. To achieve a desired low temperature, work is in progress here on a novel ***cesium hollow cathode***[5] (Fig. 3). Cesium vapor is introduced into a heated chamber made of tungsten or nickel. The atoms that adhere to the hot walls lower the metal's work function; this permits electron emission to occur at lower-than-usual temperatures. The electron emission per unit area is small, but the total emissive area is large. Furthermore, the few ions produced at the chamber walls effectively prevent the formation of a potential minimum within the chamber: this means that the electrons which are extracted all come from regions having essentially equal space potential. Hence, their low emission-temperature is not vitiated by an additional velocity spread. This is in contrast to previous hollow cathodes, which used no ions and, therefore, gave beam temperatures much higher than the wall temperature. The electrons are extracted through a small hole in the chamber. In this way beam currents adequate for TWT operation have been obtained at temperatures of about 700 to 750°K. This is in contrast to the 900°K beams of conventional TWT oxide cathodes. The next step will be to capitalize on this low temperature in an actual low noise tube.

The cesium hollow cathode has another important use. If the chamber walls are hotter than when used for low-noise purposes—say about 2000°K—no cesium adheres to the walls and the walls emit electrons by unassisted thermionic emission. If, furthermore, the cesium vapor pressure is relatively high, very many ions are produced at the hot walls. The resultant ion-electron plasma reduces the space charge in the chamber. This reduction alleviates the old problem of hollow cathodes—space-charge limitation—and so allows one to extract beams of very high current density through the aperture. Thus, this potent cathode has important applications in microwave superpower tubes. To date, 100-mil-diameter beams of 50 amps/cm$^2$ have been extracted. The efforts now are focused on raising this current density to 100 amps/cm$^2$ and to tame the attendant problems of cesium-vapor trapping and recirculation.

Another area of research, alluded to above, concerns the ***spatial decay of space charge waves*** along slowly drifting beams. Electrons in a neutralized cloud can oscillate, if disturbed, with a characteristic frequency called the plasma frequency. If the cloud moves, as in a directed electron beam, the Doppler effect produces two waves, one having a phase velocity slightly greater than the beam's drift velocity, the other slightly slower than the drift velocity. These are the "fast" and "slow" space charge waves. Their interference results in a standing wave along the beam. For example, if a beam is velocity-modulated by a klystron buncher cavity, then the RF current along the beam exhibits a standing sinusoidal pattern, the klystron catcher cavity then being put at the first current maximum. This is the "normal" situation, all of which is well known to designers of conventional beam tubes. However, recent experiments done here[6] show that this simple sinusoidal pattern changes into a decaying sinusoidal when the beam velocity is sufficiently low. The experimental arrangement is sketched in Fig. 4, together with representative results. The wave decay is attributable to multivelocity effects. When the electrons travel with a wide spread of velocities, the Doppler shift mentioned above is different for each velocity class; hence, instead of one fast space-charge wave, there are many. Each travels with a different phase velocity, and so they get out of phase with each other as they move downstream. Since the electron velocities are random, so are the phases; the upshot is a complete phase-mixing or decay of all waves except the single slow space charge wave. But this surviving slow wave has no fast-wave counterpart to beat against; hence, the power output detector sees a constant signal level. These effects occur at low beam velocities, since then the velocity spread becomes proportionately greater. In the experiments of Fig. 4, the velocity spread is due to electrostatic lens effects caused by the beam moving from, say, a 500-volt input cavity into a 50-volt drift space. Velocity spread can also arise from the space-charge depression of potential occurring in the core of very dense beams. In short, then, multivelocity effects can cause an undesirable decay of signal modulation and so must be more fully understood and controlled for proper design of beam-type power tubes.

Velocity spread also plays a role in low-noise tubes. In this case, the spread is due to the temperature of the cathode; the beam temperature is small (about 1000°K) but the drift voltage of the beam near the cathode is also small (about 1 volt). Hence the *relative* velocity spread is just as large as it is in the 50-to-100-volt beams of the preceding paragraph with their $10^5$ °K equivalent "temperatures." The multivelocity ef-

Fig. 3—Cesium vapor, evolved from the heated cesium chromate powder, is filtered before entering the cathode chamber through a fine slit. The hot chamber wall both emits electrons and ionizes the impinging cesium atoms.



fects near the cathode of a low-noise traveling-wave tube determine the $S$ and $\pi$ values mentioned earlier, and so determine the tube noise factor. Because the equations describing the noise waves in this cathode region are nasty, theorists for many years have had to settle for machine solutions—expensive and physically unrevealing. This situation has been remedied by a recent investigation at this Laboratory. Closed-form, analytical solutions have been obtained for the multivelocity noise equations;[7] special cases of these solutions also describe the aforementioned wave-decay phenomena on signal-excited beams. It is hoped that these new results will teach us how to *design* the cathode region of a TWT for optimal noise reduction.

Although the low-noise-tube art is fairly well in hand at low microwave frequencies (say, 1 to 10 Gc)—with current efforts being devoted to obtaining greater consistency and fractions-of-a-db improvement of noise factor—the situation at ultra-microwaves is less happy. This goes for *any* tube, low noise or not. Conventional tubes employ beams interacting with slow-wave circuits, and circuits become progressively more difficult to make as the frequency goes up. At millimeter wavelengths, the circuit (which for example may be a helix or ridged waveguide) must have minute transverse dimensions and must be virtually lossless. Also, since the fields decrease rapidly away from the circuit, the high-current-density beam must be kept close to the circuit. This imposes severe requirements on the beam-focusing system, lest the beam hit the surrounding circuit and produce an expensive puddle. These are formidable problems that tax the ingenuity of the engineer designing the tube and the dexterity of the watchmaker saddled with the job of putting it together. Nevertheless, a high-voltage, high-current beam is a potent source of power and the beam-to-wave mechanism should not be too quickly abandoned. The circuit, the main cause of difficulties, is fortunately not a crucial ingredient. One approach to the problem is to use two beams, one acting as the circuit for the other. In such a two-beam tube, amplification arises from the interaction between the fast wave of the slower beam and the slow wave of the faster beam. These waves may be[8] space-charge waves due to longitudinal oscillations, or they may be cyclotron waves due to the axial drift of transversely orbiting electrons in an axial magnetic field. Or, the waves may be hybrid—space-charge waves on one beam interacting with cyclotron waves on the other beam.[9] To test these ideas, a novel ***two-stream cyclotron-wave tube*** was conceived and is now being made in this Laboratory (Fig. 5). Also shown is the frequency $\omega$ versus the wave number $\beta$ of a two-beam system. Mode A uses two cyclotron waves and is a low-power mode of operation; hence, efforts will be directed toward its low-noise possibilities. Mode B is a hybrid mode and is more suitable for high-power amplification. Although this tube requires no slow-wave circuit to produce amplification, it does need circuit structures for coupling the signal into and out of the beams. However, because the tube uses cyclotron waves, one can use a very simple coupling circuit consisting essentially of two parallel plates (invented some years ago by C. L. Cuccia of The RCA Electron Tube Division for another purpose). The transverse RF field in this coupler changes the size of the orbits of the cyclotroning electrons and, thus, imparts the signal. Furthermore, if the signal frequency is very high, the cyclotron frequency—and, therefore, also the axial magnetic field—must also be high in the coupler regions; however, the magnetic field need not be high in

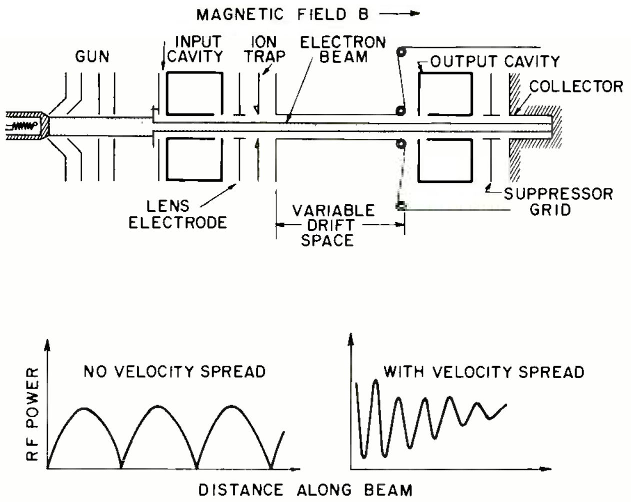
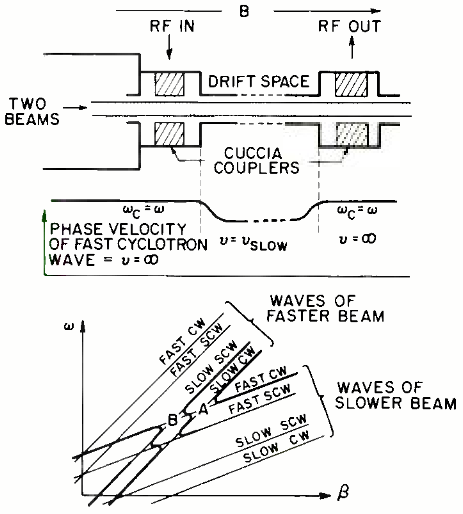


Fig. 4—The beam, after being velocity modulated by the input cavity, travels through a variable-length drift region. The standing wave pattern is detected with the output cavity. When the cavities and drift space are at equal voltages the pattern is the usual sinusoid. But when the drift space is at a low voltage so that lens effects produce a velocity spread, the pattern is a decaying sinusoid with finite minima.

Fig. 5—Two cathodes are used to produce a double-stream; the second cathode is perforated and is at positive potential with respect to the first. The axial magnetic field in the coupler region is high so that the cyclotron frequency $\omega_c$ can equal the high signal frequency $\omega$. The coupler excites the fast cyclotron wave of the slower beam. However, in the drift (or, gain) region this fast wave must be slowed down to get in synchronism with the slow wave of the faster beam. This slowing down is accomplished by reducing the magnetic field.



(A) LOW-POWER TUBE (USES TWO CYCLOTRON WAVES)
(B) HIGH-POWER TUBE (USES ONE CYCLOTRON WAVE & ONE SPACE CHARGE WAVE)

the amplification region. This greatly reduces the need for super solenoids over the entire tube.

The tubes mentioned so far derive their amplification from the conversion of DC kinetic energy of the electrons into RF energy. Thus, these tubes have limited efficiencies under usual operating conditions because the beam slows down and gets out of synchronism with the circuit wave. In contrast to these "0-type" tubes, another variety exists, called "M-type," in which the RF gain comes from the potential energy of the beam electrons. In such tubes (shown in prototype in Fig. 6) mutually perpendicular DC magnetic and electric fields are applied normal to the direction of the beam's DC drift. Because the beam is not slowed down, these ***cross-field tubes*** have high efficiency. However, when the efficiency is high the gain is low. This is mainly due to two interrelated causes: First, the decrease in potential energy that supplies the gain arises from the beam moving closer to the slow-wave circuit, which means that the beam must start out far from the circuit; but at high frequencies the RF fields are very weak far from the circuit. Secondly, to get respectable amounts of power from these tubes requires the use of large beams. There are three waves on the beam, only one of which is the growing wave. But as the beam is made thicker, the input signal excites a smaller and smaller amount of this growing wave. These considerations evolved from a recent theoretical study[10] that has also led to some possible remedies. These include the use of an auxiliary slow-wave structure as part of the sole at its input end to excite the growing wave in the region where the RF fields are high. Also, by modifying the main slow-wave structure, one should be able to reshuffle the energy in the three waves in such a way as to allocate a larger fraction to the growing wave. A tube to test these proposals is being made.

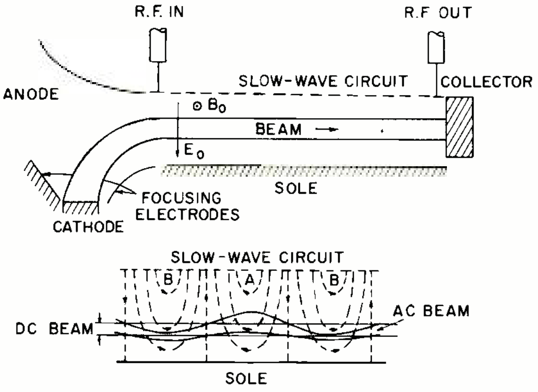


**Fig. 6—In the decelerating RF electric field regions (A) the beam moves upward, the electrons doing work against the field and losing potential energy. In the accelerating regions (B) the opposite takes place. Also, the fields tend to bunch more electrons into A-regions than into B, thus warping the beam as shown. Because more electrons thus experience a decelerative field than accelerative, there is a net transfer of beam potential energy into field energy and the field grows.**

#### PLASMAS

The reader will recall that during Scott Carpenter's orbital flight on May 24, 1962 there was a period during the capsule's re-entry when contact with the tracking stations was first lost. The cause of the expected blackout—*plasma.* The sheath of electrons and ions that covered the capsule grew so dense that the plasma frequency exceeded the frequency of Carpenter's radio and the sheath became impervious to signals. Furthermore, the plummeting capsule left behind a plasma trail that reflected the radar signals, thus confusing the trackers. This, coupled with the loss of voice communication, made it difficult for the radar trackers to decide whether they were watching Carpenter—or Carpenter as he used to be.

Controlled thermonuclear fusion, with its required fuel temperature in the hundreds of millions of degrees, also presents plasma problems—problems of confinement and of instabilities. The early enthusiasm of workers in the fusion field eventually gave way to a sober realization that these were not "just engineering problems" but, rather, were evidence of a need for a long-haul program of basic plasma research.

In addition to space technology and controlled fusion, a third stimulus for the heavy, present-day efforts in plasma research comes from microwave electronics. Here, one looks for ways of *using* plasmas rather than of fighting them. For example, particular types of electromagnetic and hydromagnetic instabilities that plague the fusion workers can, when approached with equanimity, lead to useful electronic devices. Cases in point are described below, as examples of some of the plasma topics being investigated in the Microwave Research Laboratory.

Previously mentioned was the useful interaction that results from the passage of an electron beam along an electromagnetic wave. In the ubiquitous traveling-wave tube, this interaction, or "instability," arises from the use of a metallic circuit to support the wave. The double-stream tube was cited as a special case of the TWT in which a second beam was used to replace the circuit. As a special case of the double-stream tube, one can take the drift velocity of the slower beam to zero. Thus one beam can be replaced by a stationary electron cloud or plasma. This is the beam-plasma microwave tube.

Such a tube has one distinct advantage over the conventional double-stream tube, as far as very high frequencies are concerned. The electron densities obtainable in a plasma are much higher than those obtainable in an electron beam. Thus the plasma frequency ($f_p = 9000 \sqrt{N}$ Mc, where $N$ is the density in cm$^{-3}$) can be higher for the plasma and the beam-plasma tube has a greater chance of operating in the millimeter wave region. An electron density of $10^{15}$/cm$^3$ is required if the plasma frequency is to be 300 Gc (1-mm wavelength). A plasma having nearly this density has recently been produced here by means of a ***cesium discharge.***[11] The novel feature is not the high density but the *combination* of high density and high (20-percent) degree of ionization. This means fewer scatterers are present to dampen the desired waves. The PIG (Philips ionization gauge) discharge which produces the plasma is shown as part of Fig. 7. Cesium vapor is fed into the metal cylinder, which is at 5 to 20 volts positive with respect to two annular cathodes. The positive voltage accelerates the cathode electrons sufficiently to cause a discharge. The cathode loading is small, since the emitted electrons are needed only to start the avalanche and to replenish whatever electrons are lost by recombination. Fig. 7 also shows a ***beam-plasma tube***[12] made in this Laboratory, which has oscillated at 24 Gc (12.5-mm wavelength). This tube uses helices for coupling the signal energy in and out of the beam. Eventually, for millimeter-wave work with the $10^{15}$/cm$^3$-density plasmas, couplers other than helices must be devised. Some novel schemes, using either direct coupling to a varying-density plasma or using optical "interferometer" methods, have been suggested; these will first be tested on the 24-Gc tube.

It was mentioned that plasmas exhibit hydromagnetic instabilities. One such instability occurs in a gaseous-discharge column when a sufficiently high magnetic field is applied in the direction of flow of a sufficiently high current. This instability arises somewhat as follows: If no *H*-field is present, any initial helically shaped disturbance of a current filament in the discharge soon dies out because of thermal diffusion of charges out of the dense filament. With a magnetic field, there is an additional force $j \times H$ which acts to increase the disturbance. When the current $j$ and field $H$ are high enough, this force overcomes the damping effect due to diffusion. The disturbance then grows, or "oscillates." These effects can also occur in the electron-hole plasmas existing in solids. The germanium *oscillator*[13], whose properties have been extensively investigated at the RCA Laboratories, has recently been shown[14] to operate on the basis of the same ***hydromagnetic instability*** as exists in the aforementioned discharge.

Because it behaves as a polarizable dielectric, a plasma experiences a body force when exposed to a nonuniform RF electric field. This fact has received much attention because of its possible use in confining thermonuclear plasmas and as a means of propulsion in space. A plasma has a dielectric constant $\kappa$ which differs from unity by $\kappa = 1 - (\omega_p/\omega)^2$. If $E$ is the RF field of frequency $\omega$ applied to the plasma blob, then the energy density within the plasma is $\epsilon_o E^2/4$, where $\epsilon_o$ is the free space permitivity. The potential energy of the polarized plasma is the difference between this internal energy and the energy density in the absence of plasma, $U = (\epsilon_o E^2/4) \bullet (\kappa^{-1} - 1)$. A force, $F = dU/dx = (\tfrac{1}{2}\epsilon_o E dE/dx)\, \omega_p^2/(\omega^2 - \omega_p^2)$, therefore exists if the field is nonuniform, and the direction of the force depends on whether $\omega$ is less than or greater than the plasma frequency $\omega_p$. Experimental measurements of ***plasma acceleration and deceleration*** have been made in this Laboratory, in collaboration with the RCA Astro-Electronics Division.[15] The setup (Fig. 8) consists of a mercury plasma source which shoots plasma blobs of short duration into the nonuniform field of a waveguide and thence past pick-up probes that measure the time of flight of the plasma. These measurements, performed at 140 and 350 Mc, and more recently at 2450 Mc, confirmed the theoretical dependence of the acceleration on $\omega$ and $\omega_p$. This dependence is somewhat more complicated than the simple formula above predicts, because the dielectric constant depends also on the collision frequency.

Incidentally, going back to Carpenter's radio blackout, the expression for the dielectric constant $\kappa = 1 - (\omega_p/\omega)^2$ shows why the plasma becomes reflective when $\omega_p$ exceeds $\omega$. Actually, this "dispersion" formula is altered not only by collisions but also by DC magnetic fields. Under certain conditions, a magnetic field can even cause the plasma to become transmissive. Now, some people are thinking of fitting space capsules with superconducting magnets for the purpose of shielding the astronaut from cosmic radiation. If present-day ground rules allow the astro people to propose this, then they also permit the microwave engineer to suggest that magnetic fields be used to keep the astronaut communicative, as well as healthy.

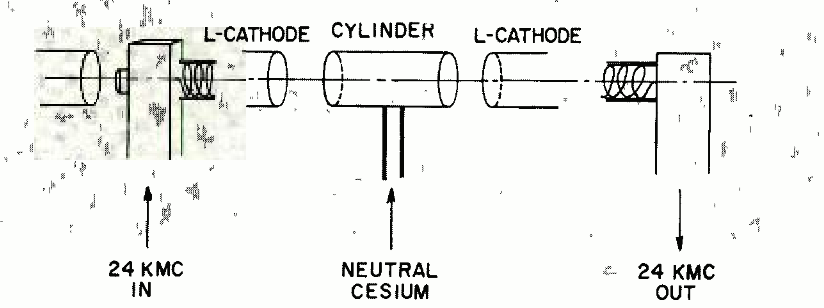


Fig. 7—A highly efficient discharge is initiated between the metal cylinder at positive potential and the electron-emissive L-cathodes. The signal to be amplified is put on the beam with a helix coupler, and removed with another helix coupler. The gain interaction takes place when the slow space-charge wave on the beam couples to the plasma oscillations of the plasma; then both the wave and the oscillations grow with distance.

### ACKNOWLEDGMENTS

Portions of the research reported in this paper have been sponsored by the Government activities listed as follows: U. S. Army Signal Research and Development Laboratory, Fort Monmouth, New Jersey under Contract Number DA36-039-sc-87393; Electronics Research Directorate, Air Force Cambridge Research Laboratories, Office of Aerospace Research under Contract Number AF19(604)-4980; Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio under Contract Number AF33(616)-8278.

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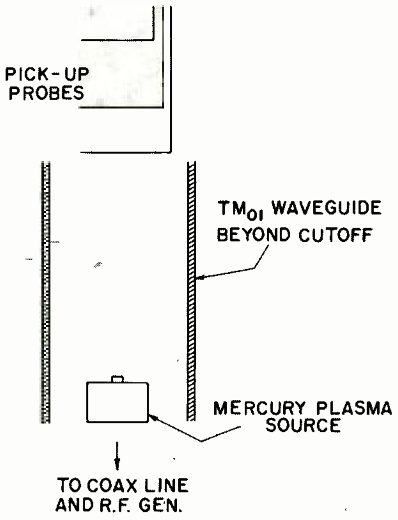

Fig. 8—A slug of plasma from the mercury plasma source is shot into the axially nonuniform RF field of the waveguide. This field accelerates the plasma and the imparted velocity is determined with the pick-up probes which measure the time of flight. The force on the plasma comes about in the same way that an ordinary dielectric is drawn into a condensor through the action of the non-uniform fringe fields.

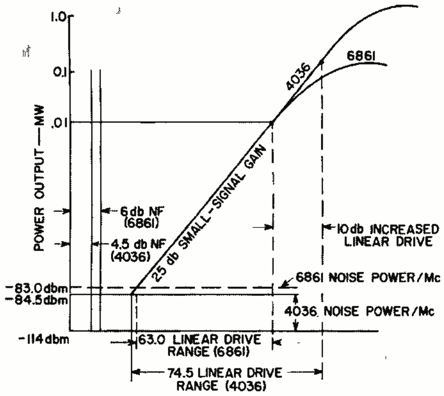

Fig. 1—4036 characteristics compared with 6861 showing increased dynamic range.

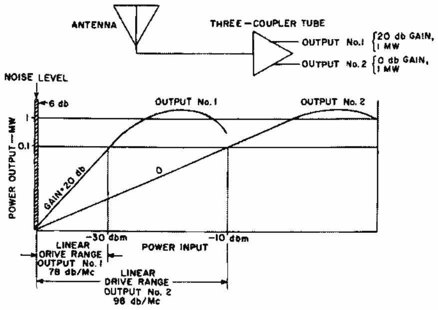

Fig. 2—Tri-coupler tube performance.

# MICROWAVE TUBES
## ...The Heart of Modern Electronic Systems

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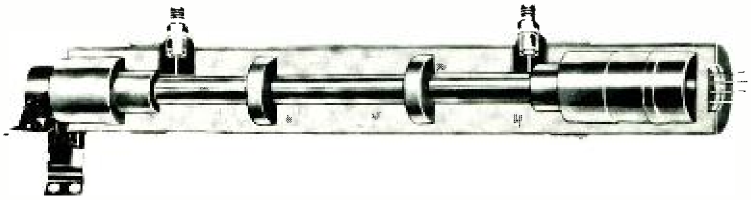

Fig. 3—Two RCA developmental traveling-wave tubes for satellite applications; above—A-1245 (Project Relay), and below, A-1228.

The capability of an electronic system to perform its function—that of converting and transforming energy into a form most suitable for its specific mission—is obviously intimately related to the nature and the capabilities of its active energy converters. Because most modern electronic systems make use of energy in the microwave bands of the electromagnetic spectrum at least for some portions of the energy conversion process, the state of the art of active microwave converters—the most intricate of the conversion devices because they contain within their confines the circuit as well as the actual energy-exchange mechanism—frequently determines the sophistication that can be built into the system.

Yet although many a system is limited in design and function by the active microwave energy converters it employs, the needs for system sophistication just as frequently act as a powerful incentive to refine microwave devices and "advance the art" to create a new limiting condition for newer, more intricate systems.

The aim of this paper is to examine this relationship in terms of specific classes of electronic systems, and to cite examples of modern microwave devices which have evolved from system needs on the one hand, and opened new design capabilities for system designers on the other. The discussion will center around devices produced by the Microwave Tube Operations activity of the Electron Tube Division; and because the most modern active microwave energy converters—those employing solid-state devices—have not yet found their way into widespread system use, it will be limited to microwave tubes.

### RADAR RECEIVERS

The development of low-noise traveling-wave tubes operating in the 30-cm and 10-cm ranges provided the radar equipment designer with an obvious means for increasing the range of his system by increasing receiver sensitivity. For this purpose, the typical low-noise traveling-wave tube of about five years ago (6-db noise figure, 20-db gain, 0.1-mw saturated power output) appeared entirely adequate. Certain types of search receivers still utilize tubes of this nature with great success. As the requirements on the system became more refined, how-about the operation of these improved receivers at *short* ranges—in other words, saturation effects in the system input stages limited the range of signals accepted by the equipment. Modern low-noise tubes, therefore, in addition to providing noise figures of 5 db or lower, must have a higher gain and a higher saturated power level. The effect of recent improvements is shown in Fig. 1, where the characteristics of RCA type 4036 are compared with those of earlier tubes to show the effect on dynamic range of the receiver.

The problem of dynamic range is not limited to receiver input tubes, but must be considered for any link in the amplifying chain of a modern broadband equipment. Equipment designers have come to take for granted the fantastic capabilities of traveling-wave tubes (in terms of gain-bandwidth product), and are forcing the design of tubes with higher and higher gain in order to increase the sensitivity of the amplifiers. However, extreme gain in a traveling-wave tube may impair its reliability; the cathode current loading may become excessive, the attenuator design may be bulky and cumbersome, and isolators may have to be used to prevent oscillations due to reflections in the input and output lines. An ingenious answer to the dynamic-range problem is provided by an RCA developmental tube now being sampled to equipment designers. In this device, an additional energy coupler provides an output at essentially 0-db gain with respect to the input. In operation, the output signal is taken either from this 0-db gain output or from the normal output terminal, depending on the magnitude of the input signal. The effect of this type of operation is shown in Fig. 2. As can be seen, over 0.1 mw of power is provided in a greatly expanded range of linear amplification.

### FIRE-CONTROL RADAR TRANSMITTER

Fire-control radar systems are another example of the close interrelationship between system and microwave tube capabilities. The type of tube, in this instance, is the multicavity magnetron. The development of tunable magnetrons permitted the design of an entire new generation of radars, whose frequency could be adjusted either by hand or by a servo-tuned drive. However, the stability problems with most magnetrons (notably the relatively high percentage of "missing output" pulses compared to the modulator trigger inputs to the tubes) placed serious limitations on the tuning speeds attainable in these systems. RCA's family of coupled-cavity magnetrons (types 7008 and 7111 among them) gave the system designer magnetrons of unprecedented stability and reliability, and for a number of years the magnetron was no longer the limiting component as far as tuning speed was concerned; further system refinements were then limited by the sophistication that could be built into the receiver.

New schemes for rapid-tuned receivers again placed a premium on magnetron tuning speed, and even servo-tuned tubes were too slow. The most recent members of RCA's magnetron family retain the coupled-cavity principle, but also employ hydraulically driven tuning mechanisms. A representative tube, RCA Dev. type A-1226, can be tuned at speeds up to 150 Gc per second over its 800-Mc tuning range in the 3-cm band.

### COMMUNICATION SATELLITE SYSTEMS

No system depends upon the reliability of its components more than that placed inside a satellite equipment, where no maintenance on the equipment can be performed and failure of a single solder connection might cause formidable expenditures and mission delays. It was for reasons of unproven reliability—rather than because of operational shortcomings—that traveling-wave tube amplifiers were *not* included in the first satellite repeaters.

Although it is true that as this paper was written no orbiting satellite contained a traveling-wave tube in its communication channels, it is very possible that by the time it is printed, a communication satellite employing a traveling-wave tube in its transmitter will have been launched—and that an RCA-designed tube will soon be in orbit.

In its design of traveling-wave tubes for satellite systems, RCA has followed a policy of self-restraint: the frontiers of "the state of the art" were deliberately shunned. Only techniques proven successful in hundreds of factory-produced tubes were employed. Cathode-current densities were held to what would be considered ridiculously low values in normal designs; cathode temperatures were kept low. All tubes were subjected to thorough electrical, thermal, and mechanical tests to flush out any weaknesses in components or assembly procedures. What resulted were "over-designed" tubes, but tubes having an indicated reliability compatible with that needed in a satellite, and incorporating mechanical and electrical features uniquely suited to the systems where they were intended to serve.

### CONCLUSION

As more systems turn to microwave frequencies to gain specific operational advantages, the requirements on major microwave components will increase both in quantity and in complexity. Microwave tubes utilizing new concepts and employing advanced design principles will have to be developed for these new equipments. If the past trend continues, it is safe to predict that as systems become more and more complicated in the mission they are intended to fulfill and in the complexity of their operation, they will use microwave tubes designed specifically for them, rather than build upon a store of existing components. In that sense, the microwave tube designer may be called upon to play an even more critical part in the design of the system of the future.

**M. NOWOGRODZKI** received his BEE in 1948 and MEE in 1951, both from the Polytechnic Institute of Brooklyn. From 1943 through 1945, he served in the United States Army in Military Intelligence. From 1948 to 1951, he worked at the Hazeltine Electronics Corporation on microwave components and measurement methods in connection with IFF, telemetering, and radar test equipment. From 1951 to 1955, he worked at Amperex Electronics Corporation on development of magnetrons and special microwave measurement techniques. He joined the RCA Microwave Tube Operations in 1955 as an Engineering Leader in charge of the development of various microwave devices, and in 1957 became Manager of Product Development. In this position, he directed all development engineering work on pencil tubes, traveling-wave tubes, and magnetrons. In August 1961, he was promoted to his present position of Manager, Product and Equipment Engineering. He is now responsible for the execution and control of all programs involving the development and applications of traveling-wave tubes, pencil tubes, magnetrons, and microwave solid-state devices, and for all activities of the Microwave Tube and Equipment Development Laboratory.

# THE BROADCAST ANTENNA FACILITY

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For the past 30 years or more, the high-quality work of antenna engineers has been a vital factor in the ready acceptance and use of RCA broadcast and television systems on a world-wide basis. This work, discussed here, ranges from designing simple single-section antennas to custom-engineered multiple antenna systems of considerable complexity. Phasing equipment, filters, diplexers, VHF, FM, and UHF antennas are some of the products designed by this group to satisfy demanding high-reliability operation, which is verified by extensive field-tests.

RCA HAS BEEN ACTIVE in the design of AM broadcast antennas since the early '30's and has contributed heavily in this field.[1-5] In 1945, when the FM and TV broadcasting industry began to expand, RCA pioneered in the design of FM and TV antennas. Subsequently, power levels and tower heights increased, and more-sophisticated multiple installations became common. Demand for increasingly higher power and greater coverage has resulted in original RCA design work in both the antenna and filter fields. Such engineering comprises not only standard product designs but numerous custom designs for special-coverage conditions. The specialized talents of the antenna engineers and, most importantly, their accumulated background has been of value to other engineers both inside and outside RCA.

## GIBBSBORO PATTERN-TEST SITE

To evaluate the theoretical antenna designs properly, a complete pattern-testing and assembly site was acquired, 40 acres in extent, near Gibbsboro, N. J. At the Gibbsboro test site there are several turntables for rotating horizontally mounted antennas during vertical pattern tests; one large turntable accommodates full-size antennas weighing up to 15 tons. A crane is available to handle all but the largest antennas; antennas up to 100 feet in height can be manipulated and mounted vertically for the taking of horizontal patterns. A few miles from the test site, a transmitter beams signals from a 100-foot tower to the antennas whose pattern characteristics are being determined.

A new building, 40 x 130 feet, is under construction so that antennas can be assembled and tested for impedance at the site, free from weather conditions.

Since 1945, over 900 antennas have been designed and built. Of this total, many antennas did not require pattern tests; these antennas were developed and assembled at another facility in Yard #4, near Bldg. 53, Camden, N. J. All 900 antennas, with the exception of the Superturnstile antennas and the FM Pylon, were assembled, tested and shipped from the two sites. In addition, 2000 harmonic filters, diplexers, sideband filters, and filter-plexers were manufactured which were designed by the antenna group.

## DESIGN PHILOSOPHY

Design philosophy is simple and straightforward. Since equipment is used almost exclusively by broadcasters, a high degree of reliability is mandatory; thus, it was necessary to design and build antenna equipment to be simple, highly

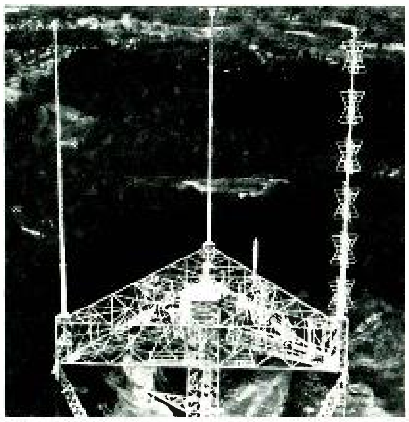

Fig. 2—Two RCA Traveling Wave antennas and one Custom Superturnstile Antenna shown on a "Candelabra" type tower overlooking the city of Baltimore. The side of one leg is 105 feet. Similar installations are located at Dallas, Texas and Stockton, California. New ones are in the proposal stage.

Fig. 3—Special traveling-wave antenna installation at the top of Mt. Washington, N. H. designed for 231-mph wind and 2 inches of radial ice. Antenna is compensated to minimize the detuning effect of ice on the outside of the 36-inch radome which encloses the antenna.

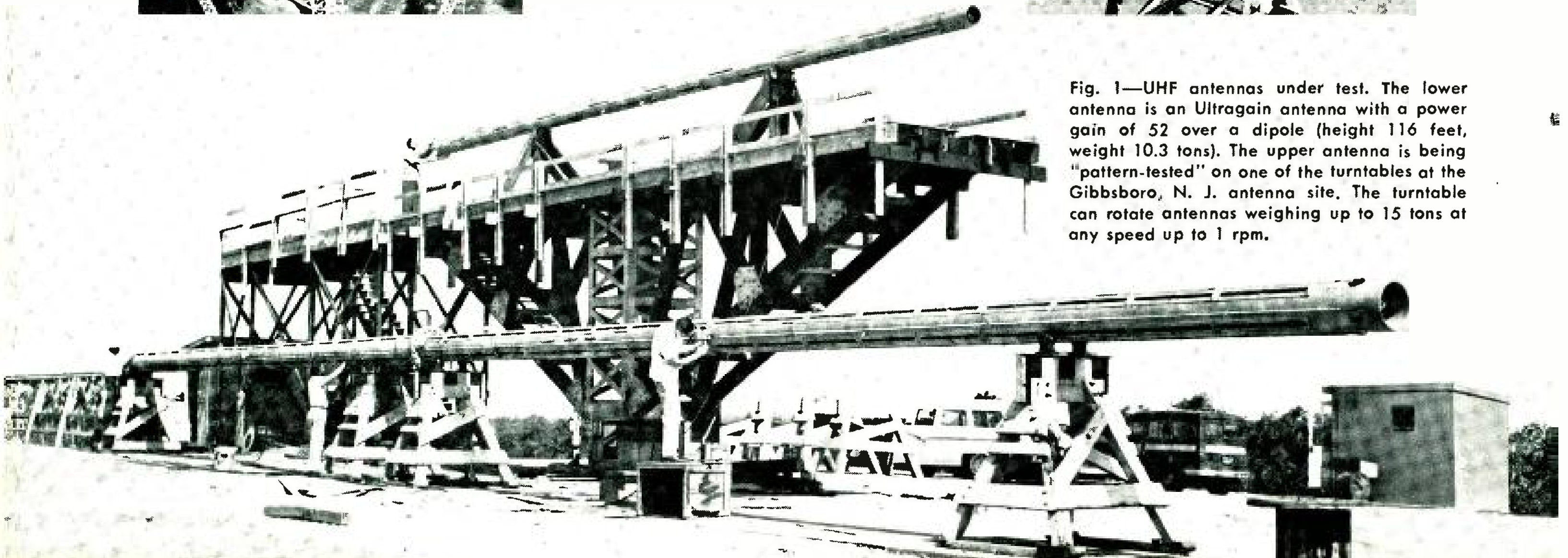

Fig. 1—UHF antennas under test. The lower antenna is an Ultragain antenna with a power gain of 52 over a dipole (height 116 feet, weight 10.3 tons). The upper antenna is being "pattern-tested" on one of the turntables at the Gibbsboro, N. J. antenna site. The turntable can rotate antennas weighing up to 15 tons at any speed up to 1 rpm.

reliable, and to meet or exceed performance specifications, at competitive prices. Following are examples of antenna designs which have captured the major percentage of the Broadcast market.

### Superturnstile Antennas

The basic development work was done by Dr. G. H. Brown (Vice President, Research and Engineering) on the Turnstile antenna[6]. The Superturnstile, an adaptation of this principle, provides a 40-percent band-width with one set of radiators and low mutual coupling between vertically disposed sections; hence, sections can be stacked with almost no interaction between them. The feed system to the radiators is of a branching type requiring four feed lines per section. Excellent performance based on thorough design work has made this antenna a standard of comparison worldwide; over 600 RCA Superturnstile antennas have been delivered.

### FM Pylon Antennas

The FM Pylon antenna was designed in the late '40's using a slotted-cylinder approach and a feed system of the branching type. A study of the characteristics most sought after by the broadcasting industry indicated that the Pylon antennas should have low windload, a minimum of projections, ease of shipment and assembly in the field, and great simplicity for general customer appeal. The slotted cylinder met these requirements and also served the dual function of being both a support and a radiator; this single simplified structure eliminated the need for supporting masts which tend to produce complications in the design.

Over a hundred of these FM Pylon antennas were delivered; many are still in use in various parts of the world after 15 years of continuous service.

### UHF Antennas

Until the early '50's, vertical power gain ratios over a dipole were of the order of 6 to 12. At frequencies in the band from 470 to 890 Mc, it was possible to obtain much higher gains with readily achievable antenna heights up to 100 feet. This meant that as many as 60 sections could be disposed vertically in one antenna; however, it was realized that higher gain antennas necessitated new developments.

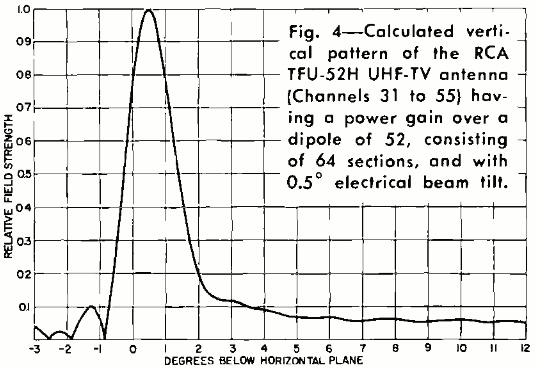

Fig. 4—Calculated vertical pattern of the RCA TFU-52H UHF-TV antenna (Channels 31 to 55) having a power gain over a dipole of 52, consisting of 64 sections, and with 0.5° electrical beam tilt.

The first was a means of feeding many sections without the use of a mechanically-impracticable branching type system. Second, higher gains generally produce vertical patterns with null areas extending well into the service area. The first requirement is met by the use of a slotted cylinder antenna and a standing-wave feed system in which a standing wave on an inner conductor energizes the slots by means of a capacitative coupler or a pick-up loop. The second requirement is met by the use of pattern synthesis wherein vertical patterns are "synthesized" by successive approximations. By choosing the proper phase and amplitude radiated from each section, it is possible to produce the patterns shown in Fig. 4. The availability of patterns of this type is unique in the industry and is a large factor in the acceptance of the RCA UHF Antenna.

In order to build UHF antennas having these relative phases and amplitudes, a single slotted cylinder section is utilized. In this section various slot lengths and coupling probes are used and relative amplitudes and phases are measured. Results are plotted on a nomograph from which data are taken for each successive section of the antenna in accordance with the pattern synthesis. The completed antennas, one of which is shown in Fig. 1, perform quite closely to the predicted pattern.

Over 140 RCA UHF Antennas having a nominal gain of 25, and 15 antennas having a nominal gain of 50, have been shipped to UHF telecasters and have rendered excellent service.

### The VHF Traveling-Wave Antenna

In the early '50's it became apparent that higher antenna gains were also desirable in the upper VHF band from channel 7 to 13. With an antenna having a gain of 15 to 18, it is possible to achieve the maximum effective radiated power of 316 kw permitted by the FCC with a 25-kw transmitter. Here again a problem of utilizing something other than the branching-feed system and the achievement of a vertical pattern without nulls was required. An additional requirement was that the bandwidth be of the order of 3 percent as compared to 1 percent at UHF. Some preliminary work on a subcontract to Ohio State University outlined the basic principles of the Traveling-Wave Antenna.

In this antenna a slotted cylinder is used because of the generally desirable characteristics outlined above. The feed system consists of a single inner conductor which sets up a traveling wave between it and the outer conductor. Pairs of slots on opposite sides of the cylinder are fed by the use of capacitive pick-up probes. Normally, because of the linear phase change with frequency across the channel, the pattern bandwidth would be rather poor. However, by utilizing the negative reactance slope of a resistively-loaded parallel resonant circuit (more capacitance is added in such a circuit at frequencies below the center of the band and less capacitance for frequencies above the center of the band), an excellent bandwidth characteristic is achieved.

The slots have a dumbbell shape in which the knobs of the dumbbell compare roughly to the inductance, and the center part to the capacitance. This parallel resonant circuit is loaded down by the radiation impedance. Two pairs of slots, each pair rotated 90° with respect to the other, are vertically disposed, one-quarter wave-length apart; thus a group of four employ the turnstile principle to produce an omnidirectional horizontal pattern. Such groups of four slots may be spaced either at half or full wavelength apart. The one-quarter wavelength spacing between pairs of slots also provides bandwidth compensation[7,8].

Since each pick-up probe is identical, a fixed percentage of the remaining energy is picked up; thus, an exponential amplitude distribution is produced to provide a null-free pattern.

The VHF Traveling-Wave Antenna has been refined to a point where it is possible to predict performance for unusual configurations; for instance, nulls can be produced at certain vertical angles for given sectors, and many types of special horizontal, directional patterns can be realized.

Forty VHF Traveling-Wave Antennas have been designed, built, and delivered to the broadcasting industry. Excellent performance has proved the design to be a standard for the industry, reflecting much painstaking engineering work.

## MULTIPLE ANTENNAS

Many multiple antennas have been built using a straight-forward approach in which complete antennas for various channels are stacked above each other. Perhaps the most well known example is the installation atop the Empire State Building antenna where five separate antennas were stacked as a unit. Many custom antennas have also been built in which two antennas are stacked using various combinations of the RCA UHF, VHF and FM antennas described herein.

A more desirable arrangement from the broadcaster's viewpoint is the so-called candelabra antenna in which three or more antennas are horizontally disposed on a platform which may be 100 feet on a side; Fig. 2 shows the Baltimore Candelabra. When using such a configuration specifications are required to guarantee the customer a particular deviation from a circular pattern. In the first two installations specifications were verified and demonstrated by means of scale models. However, in parallel with this, the theory of applying proximity effects to a candelabra configuration was formulated so that scale model work is no longer required. The theory (formulas are being programmed for a computer at the present time) has also been extended to the idea of side mounting other antennas on a single tower. The ability to share a single structure means a great saving for a broadcaster since high towers of 1000 to 1500 feet may cost $140,000 to $260,000 installed.

By the use of a 3-db coupler in which power division and phase angles can be maintained over a wide frequency range, it has been possible to construct an antenna simultaneously radiating channels 8 and 10 from one Superturnstile.

### Directional Antennas

Directional antennas have been furnished under the Federal Communication Commission's present *10-db rules* in a number of locations; some of these located on mountain ranges have provided excellent coverage over the desired service area. About 30 proposals have been made recently under FCC's proposed *drop-in* rules for VHF; requirements for these antennas are quite stringent.

Using a computer, some 125 horizontal patterns have been calculated for slotted-cylinder antennas using various numbers of slots at various dispositions, phases and amplitudes. Required patterns can also be synthesized; however, many such antennas may not be optimum designs from the viewpoint of cost and size. Hence, existing designs were utilized including some new approaches which yielded most of the pattern shapes desired. One of these approaches is the "Wedge" antenna which uses two radiating vertical sheets. Another is the slotted tower which has less windload than a slotted cylinder due to its open construction, uses standard construction techniques and by its square shape may modify the slotted-cylinder pattern in a desirable fashion.

## FILTERS

In addition to the antenna engineering work performed by this group, a number of engineers are proficient in designing various types of filters. Among these are harmonic filters needed to reduce the harmonic level to the stringent requirements of the FCC. These are made for various power levels for frequencies used in broadcast range from 54 to 890 Mc. Various filters have also been designed to combine two or more FM transmitters. One such system was proposed for the Empire State Building where seventeen transmitters were to be combined into a single quadrature-fed antenna.

For television broadcasting, various filters are required for attenuating a portion of the lower sideband but maintaining the pass band within a fraction of a db. These filters have been designed for various power levels up to 50 kw for all VHF television channels. Filters are also required to combine visual and aural transmissions. Both *bridge-type* for quadrature-fed antennas and *notch-type* for antennas having a single feed point have been designed for power levels up to 50 kw. Other filter units combine the function of a vestigial sideband filter and that of combining visual and aural signals into a single unit; such a unit is known as a *filterplexer;* reject cavities are disposed in two parallel runs and terminated with balun units. Filterplexers have been designed for all television channels from 54 to 890 Mc. Excellent performance with a high degree of reliability has been obtained.

Filterplexers must maintain an amplitude response within 1.5 db of picture carrier over a 4.7-Mc region. At 0.32 Mc above the edge of the visual band a rejection of 30 db must be obtained. At UHF, extremely high slope cavities are required to accomplish this rejection level which have been of the spherical type. Since these are limited in power in the mode used, a special waveguide filterplexer was designed for *WUHF*, experimental FCC station, to handle a power level of 50 kilowatts. With sufficient cooling, the power rating can be extended to 150 kw.

Various measuring devices have also been designed such as directional couplers used for both transmitter and antenna protection. A complete set of RF loads at various power levels and frequencies have been designed including UHF loads for 25-kw and 600-kw continuous wave operation.

## SUMMARY

Many new challenges, such as directional antennas, the combining of many antennas into one structure for antenna farms necessitated by air traffic patterns, antennas capable of radiating 5 Mw and accompanying filter designs for the expanding UHF field, and similar problems are being met every day. In addition, many unusual requirements have been met and solved such as the Mt. Washington Traveling-Wave antenna shown in Fig. 3. The Mt. Washington antenna was designed for 231-mph winds and a 2-inch radial ice specification; the antenna was completed on a crash program for erection in early October before the site became inaccessible. At this location rime ice forms on cold surfaces from fog blowing over the mountain top; such coatings may melt and refreeze to form solid "blue" ice several feet thick.

RCA antennas continue to have a wide acceptance in the industry, based primarily on their performance. The basis for such accomplishments lies in the ability of our antenna engineers.

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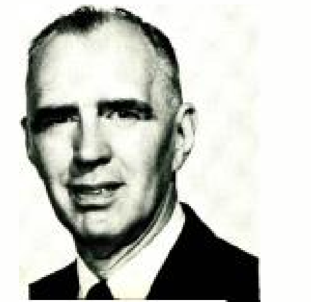
**H. E. GIHRING** received his BSEE from Washington University in 1926. From 1926 to 1928, he served as Electrical Assistant in the Signal Corps. In 1929, he joined the Technical and Test Dept. of RCA. In 1930, he was transferred to Camden in the newly formed Broadcast Transmitter Section, and from 1930 to 1935 he was assigned to propagation and antenna work. In 1936, he was transferred to New York for a year to work on the Empire State television transmitter installation, and from 1937 to 1940 was engaged in television transmitter development. In 1940, he was assigned to the supervision of the Television Transmitter Group which expanded into Radar activities until 1944. From 1944 to the present time, he has been engaged in television transmitter and antenna work in a supervisory capacity and is presently the manager of the Broadcast Antenna Group. Mr. Gihring is a Senior Member of the IRE.



**Editor's Note**—The author and members of the Applications Laboratory are responsible for pioneering and developing many applications for transistors and semiconductors both inside and outside RCA. The Applications group has contributed substantially to the reputation for quality and uniformity enjoyed by RCA semiconductors in commercial fields and for military applications. In this paper, the use of transistors for auto-radio applications is traced from the power transistors used in hybrid receivers in 1955 to the development of the RCA drift-field transistors for present-day applications.

# SEMICONDUCTOR ADVANCES IN AUTO-RADIO APPLICATIONS

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With major automobile manufacturers now in the process of converting to all-transistor radios, it is probable that 1962 will see almost total conversion from "hybrid" receivers to all-transistor sets. This change-over is a significant achievement for the semiconductor industry, both technically because auto radios present rather exacting standards of performance, and commercially because the automobile business, with its total volume of six million receivers per year, represents an important new market area. Heretofore, the major market for semiconductor devices in consumer products was portable battery-operated radios, which have a gross annual volume in the United States of approximately five million receivers.

The Semiconductor and Materials Division has played a major role in accomplishing the conversion to all-transistor automobile radios through the parallel development of transistors especially designed to meet the requirements of auto receivers and transistor auto-radio circuits having high performance at low system cost. This paper reviews the evolutionary transition from tubes to transistors in auto radios from both a technological and an economic point of view—from the early hybrid sets having only one transistor in the output stage, through the costly eight- and eleven-transistor receivers, to the present high-performance five-transistor receiver. The latter, which uses RCA drift-field transistors, highlights this successful transition.

## INITIAL APPLICATIONS

By 1955, transistors had already made major penetrations into such consumer markets as hearing aids and portable radios. In these areas, the low cost of operation more than compensated for the fact that transistorized units had a higher initial cost than tube-operated counterparts. The reduced size and weight of transistorized equipment were also of prime importance in this type of equipment. These consumer areas were such a natural market for transistors that the conversion from tubes was accomplished in less than two years.

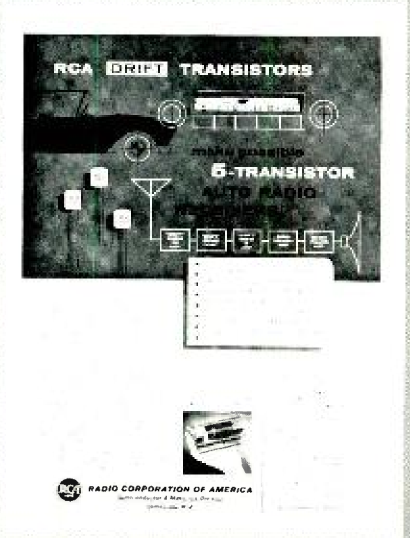
Once the problems associated with the early development and production of portable receivers had been resolved, the Semiconductor and Materials Division analyzed future markets to determine which were likely to reach commercial maturity first. These studies indicated that automobile radios would be the next important consumer product area. From a technological point of view, the frequencies involved presented no great problem; the transistors then being manufactured were already capable of the required frequency performance. In addition, transistors offered major advantages for auto-radio service such as instant play, smaller size (which permitted styling innovations), better resistance to shock and vibration, and freedom from the expensive maintenance problems usually associated with auto radios.

Economically, the volume of the auto-radio market was large enough to warrant the engineering effort required to meet the more exacting performance objectives. It was recognized at the outset, however, that it would be more difficult to justify the use of transistors in auto receivers than in dry-cell battery-operated equipment because the cost of operation (i.e., life of the storage battery) would not be significantly affected by the auto radio. While auto manufacturers readily admitted that the instant-play aspect, the smaller size potential, and the greater reliability were attractive features, they felt that it was not practical to provide these features at an appreciably higher cost for the receiver.

As a result, the performance of broadcast transistors had to be greatly improved so that receivers could be built without extra stages of amplification. In addition, transistors had to sell at prices comparable to tube prices. At the time these objectives were established, auto radios using transistors had three or four extra stages and were considerably more expensive than their tube counterparts. From 1955 through 1957, several auto manufacturers produced, in limited quantity, eight- or eleven-transistor radios for their deluxe autos; these receivers sold at approximately 1.5 to 2 times the cost of tube-type radios with better performance.

In 1957, a combination portable-auto radio receiver was introduced, consisting of a removable portion that plugged in and out of the dashboard. This unit performed as a portable radio when removed from the auto, and served as the tuner and low-power audio stages of the auto receiver when connected to a larger speaker and power-amplifier system per-

Here's a dramatic new
sales extra you
can demonstrate
at the flick of a switch



manently installed in the automobile. Although this arrangement achieved limited success, it was a rather costly approach because it required an additional small speaker, complicated switching arrangements, and an extra tuning capacitor (the ferrite antenna could not be tuned with the same system used with the auto whip antenna). This development did, however, provide valuable field and manufacturing experience, and was one of the most interesting interim approaches.

Although these attempts were important stepping stones in the evolution of an all-transistor auto receiver, they failed primarily because the semiconductor devices then available were not capable of matching tube performance on a stage-for-stage basis.

### HYBRID RECEIVERS

In 1955, while attempts were being made to develop an all-transistor receiver, the tube industry introduced special tubes for operation at 12 volts. Because these tubes could be operated from the 12-volt supply system of an automobile, a hybrid receiver could be constructed in which the output stage included a power transistor and the remaining RF and audio stages included the new 12-volt tubes. Because the relatively higher cost of the power transistor was offset by the elimination of the vibrator and other power-supply components, the over-all automobile receiver cost remained the same.

In later auto radios, the tube-type second-detection rectifier was replaced by a semiconductor diode, and the driver tube was replaced by a small audio transistor. Less-expensive, lower-gain output transistors could then be used because the transistor driver could produce more driving power than its tube counterpart. The transistors used in the audio-driver stage also eliminated some microphonic problems which were particularly evident when an auto was driven over concrete highways having tar strips.

The first hybrid sets, however, were plagued with performance problems because the distortion was higher than in comparable all-tube sets and the performance of the 12-volt tubes did not quite match the operation obtained at higher plate voltages. In addition, the reliability of the power transistors in the early hybrid receivers was adversely affected by poor seal quality, inadequate protection against voltage transients which could occur during abnormal operating conditions, and other device problems relating to the quality of the junctions; these factors were not well understood or controlled at that time. Although the initial reliability was disappointing, subsequent improvements in transistors established them as very reliable components. (Field failure rate for transistors in auto receivers averages less than 0.08 percent per year.) From 1956 to 1960, the early difficulties were largely overcome, and there was a very rapid swing in the industry to hybrid receivers despite their performance limitations.

As the cost of the power transistors dropped as result of yield improvement and other manufacturing economies, the cost of the hybrid receiver gradually approached that of the all-tube counterpart, and eventually became even lower. Although the hybrid receiver failed to offer instant play or other advantages of the all-transistor set, it did eliminate the vibrator and offered some improvements in reliability and space requirement. In addition, it gradually established a feeling of confidence on the part of radio-receiver manufacturers in the products provided by the semiconductor industry.

From a technological standpoint, the advent of the hybrid receiver helped to set the stage for the subsequent introduction of the all-transistor set because the audio system was almost the same. However, it made the economic problem of replacing the RF and IF tubes with transistors of equivalent performance more difficult. This difficulty was increased by the continued development of improved tubes for the RF and IF sections of hybrid receivers. The alloy transistors used in portable radios at that time had somewhat poorer signal-to-noise ratios than tubes and were not capable of furnishing sufficiently high stable stage gains to permit a single IF stage. As a result, portable receivers using these transistors invariably used two, and occasionally three, IF stages. It was obviously necessary that greatly improved transistors be developed for the RF, converter, and IF-amplifier stages so that the same sensitivity and signal-to-noise ratios could be obtained without adding additional IF stages to the all-transistor receiver.

### DEVELOPMENT OF DRIFT-FIELD TRANSISTORS

RCA had developed a line of higher-frequency drift-field transistors, primarily for military and industrial use, which offered the promise of higher stage gains and better signal-to-noise ratios. Although these transistors were costly because of difficulties in controlling diffusion and problems associated with their very small geometry, it appeared possible to design a less-expensive, larger-geometry drift-field transistor for the broadcast band to meet auto-radio objectives. Accordingly, in 1957 the Semiconductor and Materials Division initiated a major program which envisioned the drift-field transistor eventually being produced at the same or nearly the same cost as the alloy high-frequency types.

R. M. COHEN graduated from RCA Institutes in 1940 and joined RCA Tube Division as a laboratory assistant the same year. He attended evening school at the Newark College of Engineering and Stevens Institute, and was promoted through engineering ranks to become Manager of the Semiconductor Applications Laboratory in 1953. Mr. Cohen assumed his present position in 1955. In 1957, Mr. Cohen was one of eight employees to receive RCA's AWARD OF MERIT. He is a senior member, IRE.

At the outset, the manufacturing process for the drift-field transistors was considerably more complex than that for the alloy-type transistors. An intensive cost-reduction program was initiated which analyzed and improved each process used in the manufacture of drift transistors until the over-all yield of the drift types equalled that of alloy types. This approach not only reduced the cost of the product, but also improved its uniformity and reliability. Wherever possible, standard procedures and parts were substituted for special components to achieve cost reduction. For example, at only a slight reduction in performance, the auto-radio drift transistor types were changed from the four-lead in-line TO-7 enclosure to the three-lead TO-1 enclosure which was standard for other high-volume battery-operated portable types.

The performance of alloy and drift-field types is compared in Table I. The additional 14 db of gain provided by the drift-field transistors in the converter and RF stages is approximately equal to that lost by the elimination of one IF stage. The extra gain results primarily from the greatly reduced feedback capacitance and the higher input and output impedances of the drift types at the operating frequencies. (The graded-base mechanism techniques applied to drift-field transistors have been described in the literature, along with the general principle of the built-in electric field and its effect on reducing transit time of injected carriers.[1])

The details of the RCA auto-radio transistor program were first described

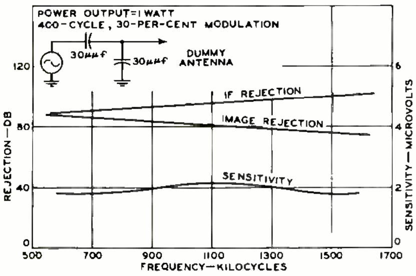


Fig. 1—Sensitivity and rejection characteristics of five-transistor receiver.

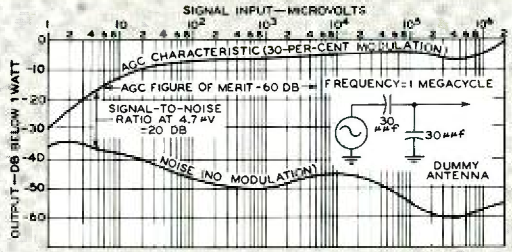


Fig. 2 — AGC and noise characteristics of five-transistor receiver.

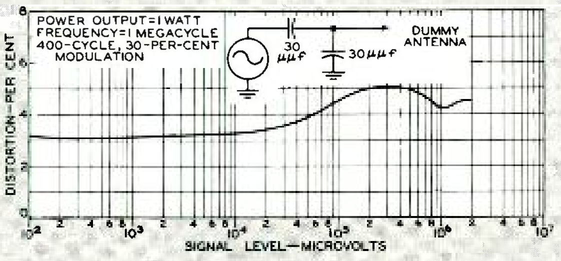


Fig. 3—Distortion of five transistor receiver as a function of signal level.

in a paper presented at the 1958 IRE National Convention in New York.[2] This paper explained the advantages of the drift-field transistors and provided information on the design of practical auto-radio receivers built around them. With the release of the paper, interest in all-transistor auto radios greatly increased. Because of this reaction, RCA was encouraged to accelerate device and circuit development efforts. As a result, a complement of drift-field transistors for auto radios was commercially introduced at the 1959 IRE National Convention, and complete details were presented on the design of a five-transistor auto receiver.[3] The performance characteristics of this receiver are shown in Figs. 1 through 4. (Circuit details may be found in Ref. 3.)

During 1959 and 1960, further improvements were made in receiver circuits, and further advances were made in cost-reduction programs on the device. An extensive advertising program aimed toward the automobile industry was also launched concurrently with the technical program.

Meanwhile, many of the smaller independent auto-radio manufacturers were producing all-transistor auto radios using RCA drift-field units. Unlike the early experiences with the hybrid receivers, this program was successful at the start, with no serious production or field-life problems. The most enthusiastic advocates of the all-transistor receiver have been those companies who actually manufacture and sell the sets.

## FORECAST

RCA's future efforts in the development of new auto products will consist partly of support of a trend toward AM-FM receivers and FM converters. The Semiconductor and Materials Division has already developed a new drift-field FM converter (RCA Dev. No. TA1990), as well as an improved line of FM transistors (2N1177 to 2N1180). The application of these transistors in an AM-FM auto radio was described in a paper presented at the 1961 IRE-EIA Radio Fall Meeting.[4] Although the AM-FM receiver is a luxury item in the United States. FM is the major medium for radio entertainment broadcasts in areas such as Germany. Consequently, this development is of considerable interest both for domestic and foreign markets.

**Table 1—Chart of transistor performance characteristics (all values taken at 12 volts).**

| Type | $R_{in}$ (ohms) (262.5 KC) | $R_{out}$ (ohms) (262.5 KC) | $R_{in}$ (ohms) (1.5 MC) | $R_{out}$ (ohms) (1.5 MC) | $C_f$* (μμf) | Maximum Usable Gain (db) $IF_1$ (262.5 KC) | $IF_2$ (262.5 KC) | Conv. (1.5 MC) | RF (1.5 MC) |
|---|---|---|---|---|---|---|---|---|---|
| ALLOY | (a) 1000 | (a) 30,000 | (a) 300 | (a) 12,000 | 11±4 | (b) 24 (neutralized) | (a) 27 | (b) 30 | (a) 18 |
| | (b) 1500 | (b) 45,000 | | | | | | | |
| DRIFT | (c) 2700 | (c) 400,000 | (a) 1,000 | (a) 180,000 | 2.7±0.7 | — (unneutralized) | (c) 37 | (b) 37 | (a) 25 |
| Increased gain from use of drift-field units | | | | | | —14(d) | | 7 | 7 |

(a)—Current at 1.0 ma
(b)—Current at 0.65 ma
(c)—Current at 2.0 ma
(d)—one stage of drift IF vs two stages of alloy
*—feedback capacitance (Cc to b) when transistor is used in common-emitter mode.

## ACKNOWLEDGMENT

In addition to the engineers whose papers are referenced, the author wishes to pay particular credit to the following Semiconductor and Materials Division personnel who participated in the programs described: Richard Denning, John W. Englund, Lewis A. Jacobus, Harold V. Kettering, Robert E. Kleppinger, David Wells, Frank A. Wildes, and John D. Young.

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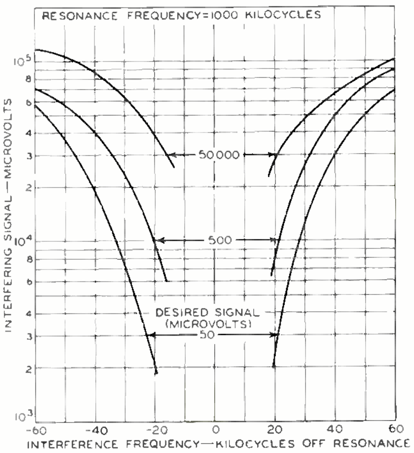
Fig. 4—Crosstalk characteristics of five-transistor receiver for signal levels of 50, 500, and 50,000 microvolts.



# A TRANSCONTINENTAL MICROWAVE SYSTEM

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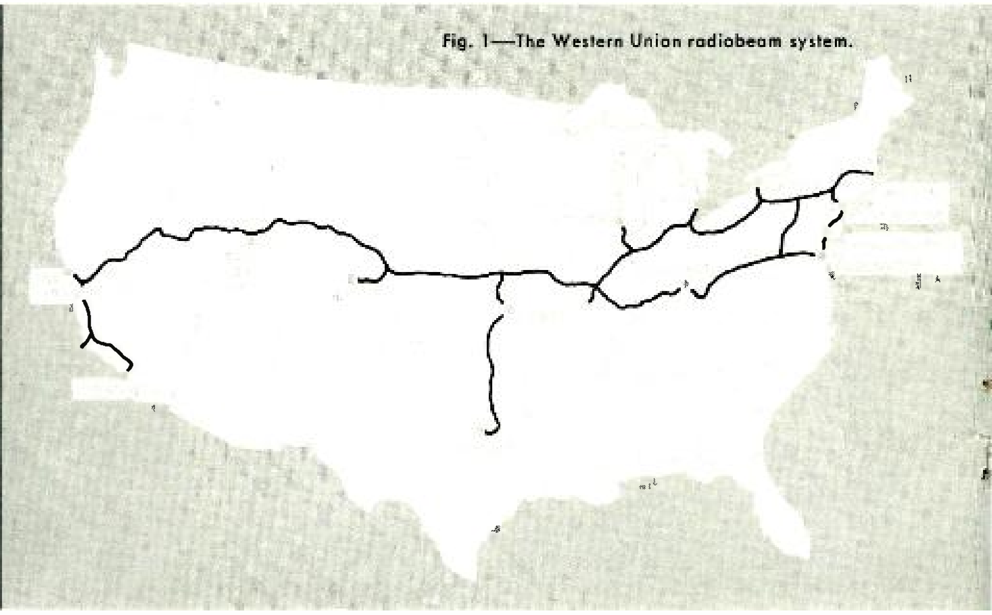

Fig. 1—The Western Union radiobeam system.

During 1962 and 1963 RCA will supply 236 relay stations equipped with MM-600-6 microwave equipment to the Western Union Telegraph Company, which will form a transcontinental network 5300 miles long—the largest commercial system installed in one operation. This project has involved RCA and many subcontractors from the microwave industry in unusually large production quantities of high-quality pieces such as: 1000 travelling-wave tubes, 3000 waveguide filters, 9000 varactor diodes, and a similar quantity of ferrite devices of state-of-the-art performance. The MM-600-6 has given great impetus to the varactor multiplier art and has reduced tolerance on many other microwave devices.

COMMON-CARRIER COMPANIES such as RCA Communications, Inc., Bell Telephone, independent telephone companies, and Western Union Telegraph sell communication services for profit. To perform these communication services, line-of-site microwave offers the cheapest and most reliable overland communication circuits for telephone, telegraph, television, and data. Also, the Government leases such services from the common carriers — SAGE, BMEWS, and satellite-derived signals are carried over these commercial systems, together with normal business traffic.

#### COMMON CARRIER NETWORKS

Common-carrier networks are designed in the form of a high-capacity "backbone" circuit with low-capacity spurs. Radio equipment for backbone service must be of very high quality, high reliability, and high capacity (capacity is measured in terms of the standard 4-kc-wide telephone channel; such a channel may be used for a single telephone conversation or eighteen telegraph channels). The original equipment for long-haul service was the TD-2 manufactured by Western Electric for the Bell Telephone Co. This equipment carried up to 480 voice channels over long distances. Now, it is typical to install systems of 600, 960, 1200 or even 1800 voice-channel capacity. There are technical and economic reasons for this trend toward higher capacity equipment. *Long circuits* having an average traffic density of 240-voice channels may have heavy loadings as high as 1000 voice channels on some sections of the network. (*Long circuits* refers to the complexity of systems rather than route distances; the term may apply equally well to systems spanning continents or shorter complicated networks with many interconnecting spur routes.)

The common carrier must conserve frequency spectrum. By carrying more traffic on a given radio frequency carrier, more-effective use is made of the transmission medium. It can be shown that there is an economic advantage in transmitting a large amount of traffic per radio site. The site cost (buildings, towers, access roads and primary power sources) is essentially the same for 240-channel equipment as it is for 600-channel equipment; in either case, site cost is a major part of the total cost. Therefore, considering only capital investment, the common carrier will find it economical to install higher-capacity equipment in spite of its higher price. Maintenance and power costs may not be greater in the case of the higher-capacity equipment, yet the potential revenue may be doubled.

These considerations led Western Union to purchase RCA MM-600-6 equipment of 600-voice-channel capacity. (MM-600-6 means *M*icrowave *M*ultiplex *600* voice channel at *6* Gc.)

#### TYPES OF RADIO EQUIPMENT

Most microwave equipment (aside from RCA's MM-600 and that produced by Western Electric) has used a klystron as the transmitting power generator and frequency modulator. To use a klystron, the incoming FM signal must be demodulated at a repeater and then remodulated at the next transmitter. Such a repeater is called a *remodulation repeater.*

Although suitable for short-haul service with up to 240 channels, the remodulation repeater can never provide the low distortion and high-gain stability (baseband-to-baseband) over the distances required by common carriers for their long-haul circuits. Equipment suitable for such long-haul service is provided by a *heterodyne repeater system,* in which the incoming signal is not demodulated, but merely translated to a new microwave frequency to be reradiated; MM-600 equipments are of this type.

To assist in the international connection of microwave relay equipments, the International Telecommunications Union, through its radio committee CCIR, recommends minimum performance and standardizes impedances, levels, frequencies and frequency deviations. For the benefit of common carriers, CCIR defines performance in the form of heterodyne repeaters. Performance is referenced to a 1550-mile circuit containing nine modulation sections. Each modulation section averages some 170 miles and contains a modulating and demodulating terminal at each end, with five heterodyne repeaters between; the average hop in a microwave system is about 30 miles. CCIR requires that the weighted signal-to-noise ratio in the worst telephone channel be 60 db or greater over a 170-mile modulation section (equivalent to 25 dba at a zero-traffic-level point; *for discussion of dba, see* W. J. Connor, *Engineering & Research Notes*, this issue). Performance specification must be met for 80 percent of a month during which fading is severe. Therefore, the radio equipment designer must make sure equipment can meet the specified values with a fade of about 5 db introduced on every hop. The MM-600 was designed to meet these conditions.

### HISTORY OF THE MM-600-6

When RCA started development of an experimental microwave system (MM-X); the objective was 240-voice channel capability according to CCIR standards, but with the ultimate requirement of 480 voice channels or video over a few hops. Before the project was half completed, the performance objectives were increased to 600 voice channels or color television for transcontinental distances. The first MM-600 equipment developed was for operation in the 1700-to-2300-Mc band.[1] Subsequent designs retained the simple basic principles. Equipment was sold to the Canadian National Telegraph for use on the CBC-TV network in eastern Canada.[2] It was put into service in July 1960 and extended in April 1961. Development continued, and a later version was sold to the same customer for a long-system connection to Alaska of some fifty stations, which was delivered on July 1, 1961.

In the middle of 1959, Western Union sought microwave equipment which would provide them with a video system paralleled with a message system of 600-voice-channel capacity. They were interested in very high reliability and in using diversity protection to meet CCIR performance standards. RCA had the basic design completed for such equipment and contracted to design a 6-Gc version retaining as much of the modulation, IF and power supply techniques as possible from the original MM-600 design.

The new transcontinental Western Union system, now being installed, connects Los Angeles and Boston, with spurs to New York, Philadelphia, Washington, Dallas, and Denver, with a two-way diversity 600 voice-band message circuit. A loop is provided connecting Cleveland, Detroit, and Chicago to the east-west trunk (Fig. 1). Western Union is responsible for a major share of the system planning and implementation. Western Union is also surveying the route, optioning land, obtaining licenses, providing buildings, roads, standby primary power equipment and towers with passive reflectors. RCA is providing and installing the MM-600-6 radio equipment, fault alarm and order-wire equipment, antennas, and waveguide feeders. RCA is responsible for the performance from radio input to radio output of the system on a modulation section basis.

### PROJECT ADMINISTRATION

After the award of the MM-600-6 microwave program, a project group including financial, project control, contract administration, and installation personnel was established. It consists of 12 people in the home office and 40 RCA people assigned to the field, in addition to several electrical contractors supporting the field operation.

Regional Field Offices were established in California, Kansas and New Jersey. Arrangements were made to use 27 warehouses across the country for the temporary accumulation of equipment. Installation planning included scheduling of installation, plans for efficient methods of field operation, and a program for training personnel.

The factory production of the MM-600-6 microwave equipment was the largest for high-quality commercial communication equipment ever scheduled, requiring almost 1000 of each major unit. Thousands of tubes, varactors, and diodes were used. The reporting and supervisory equipment alone used over 50,000 transistors throughout the system. The field program also poses logistics problems involving material and many people.

### MM-600-6 FEATURES

In planning the MM-600-6, decisions had to be made as to the choice of travelling-wave-tube (TWT) characteristics, the means of combining several transmitters and receivers into a common waveguide, and the choice of waveguide flange. Some problems arose from the specification requirement that more RF channels be added to the antenna system at a later date without interrupting traffic. Other specifications related to reliability of equipment and its potential use at higher channel capacities with minimum modifications.

The requirement for RF channel expansion means that the roof-mounted parabolic antennas presently used in conjunction with tower-mounted reflectors must be exchanged at a later date for tower-mounted antennas and long waveguide feeders. Specifications also called for the multiplexing network (or branching filter assembly) to be constructed on a building-block principle, since rework of installed networks is not feasible.

The branching-filter system must have a low reflection coefficient (around 2 percent) to minimize echo distortion over an 8-percent bandwidth with an essentially fixed phase characteristic; such performance must be maintained over a wide environmental range.

The technique of constant-resistance hybrid branching was considered but discarded in favor of a ferrite circulator system. It was also decided to machine the waveguide band-pass filters from solid Invar stock for temperature stability and for the ultimate in mechanical rigidity. Fig. 2 shows the circuit used, with a stage of expansion depicted in phantom. A typical repeater installation, Fig. 3, shows the branching network suspended overhead. Where possible, aluminum die-castings and tubing have

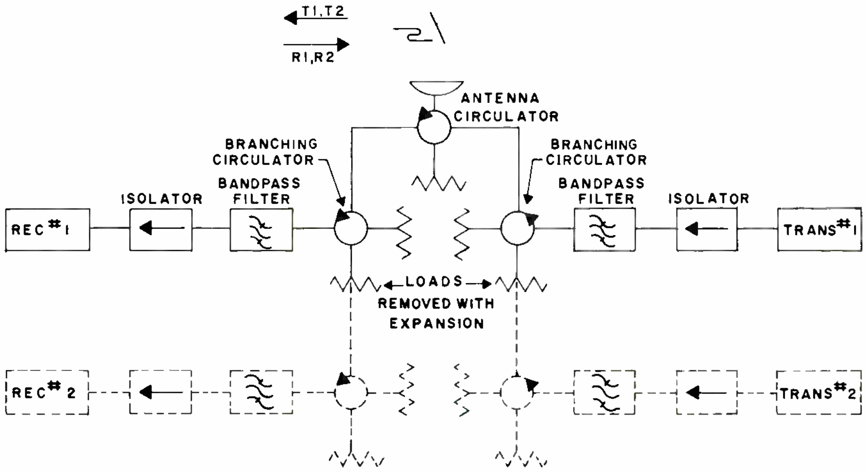
Fig. 2—Ferrite circulator branching network (expansion stage shown in phantom).

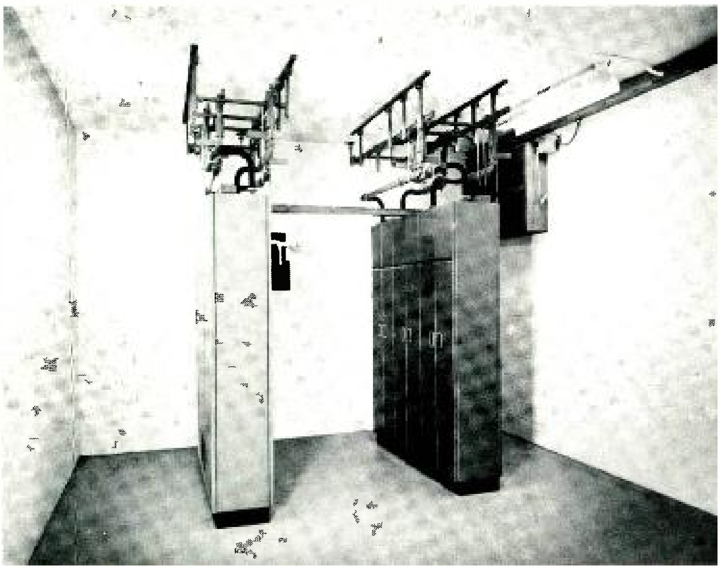

Fig. 3—A two-way diversity repeater installation with branching network suspended overhead.

been employed for light weight, necessitating stainless-steel wafers and hardware at dissimilar metal joints. These networks constituted one of the few occasions that the designer was faced with intermodulation distortion as a significant problem in a four-port circulator. (It is normally accepted as a linear device.)

Flanges for the waveguide joints were designed for optimum electrical performance, allowing pressurization with minimum excess periphery. A half-height gasket, cemented in a groove, allowed mating with either a similar type or the flush surface of a flat-flange or a pressure-window wafer. This technique permitted removal and replacement of waveguide sections or components within a long run without lost or bruised gaskets.

Since the heart of this equipment is the TWT, great care was devoted to the determination of specifications, including the high-voltage source. From the standpoint of economy, it was necessary that the tube envelope be field replaceable. The focusing mount was required to be of the periodic type from the standpoint of weight, stray magnetic field, and saving of solenoid power. To avoid forced-air cooling in the equipment, the requirement of convection cooling was added. Before soliciting bids for development and production, these features, coupled with a warranty and stringent electrical specifications were selected to accommodate several times the initial voice-channel capacity. Eleven sources were evaluated over a period of six months before letting the contract for several million dollars worth of operating and spare tubes; fourteen months later, production was geared for more than one hundred assemblies per month.

Previous experience on the 2-Gc design program proved valuable in planning the power supply for the new product. For example, TWT's are particularly sensitive to regulation and ripple voltage and to the order of appearance of electrode potentials. Therefore, the magnetically-regulated supply included a simple programming feature in addition to the usual protection circuits.

Although less than ten percent of the equipment installations are manned sites, it is necessary that the equipment be attractive. The equipment chassis are housed in cabinets fitted with removeable dual doors magnetically latched. A common mounting base serves as a plenum chamber for a small blower used to minimize cabinet temperature rise. A typical two-way repeater is provided in a triple cabinet arrangement with the radio equipment located in the outer racks and common units in the center. The diversity (or protection) channels are placed in an identical triple cabinet arrangement with the bays of the two groups facing each other across a central aisle and connected by an overhead duct. Each unit is removeable from the rear of the cabinet as a convenience to clear cables, fittings and waveguide plumbing (Fig. 3).

### EQUIPMENT DESCRIPTION

The basic radio terminal station is shown in Fig. 4. Local oscillator frequencies for both *up* and *down* conversion are derived from crystal controlled oscillators, with subsequent solid-state frequency multiplication. The input signal from the transmitting multiplex equipment is amplified and fed to a frequency-modulated oscillator (FMO). The 70-Mc output of this FMO is applied to the transmitter, where it is limited and converted to a microwave carrier by the frequency-doubling up-converter. This FM carrier is amplified by the TWT before application to the radio branching network (Fig. 4).

The received signal from the opposite direction is heterodyned to 70 Mc and amplified by a gain-controlled IF amplifier. Adjustable phase equalization is provided before connection to the FM demodulator. The recovered baseband signal is amplified and applied to the receiving multiplex equipment.

As shown in Fig. 5, 100-percent fallback is provided by frequency diversity; a ratio-squared combiner is employed at the receiving terminal. Failure of one modulator at the transmitting terminal automatically connects the remaining modulator to both radio beams, maintaining system diversity.

In discussing the terminal station, we have covered the basic elements of the simple heterodyne repeater shown in block form in Fig. 6. With the present MM-600-6 system, equipment protection is also provided at *through* repeaters.

Automatic switching is shown functionally in Fig. 7; failure of one receiver causes automatic connection of both transmitters to the remaining receiver. In the event of a complete loss of incoming signals, 70-Mc standby oscillators provide system continuity and fault transmission. Full-duplex party-line service and fault tone transmission are accomplished by phase modulating the *transmit local* oscillators. A typical two-way repeater bay is shown in Fig. 8.

### FAULT-ALARM FACILITIES

Supervisory control becomes increasingly important in any microwave system as the extent and complexity of the system increases. Originally, the system provided ten manned stations among a total of about 140, a ratio of 1:14. Presently, the ratio is approximately 1:40. Since each manned station must be attended around the clock, this substantial reduction in the number of manned stations results in a significant reduction in personnel. However, this saving can only be realized when supervisory equipment at the manned stations is sufficiently comprehensive and of the highest reliability; this describes the character of the RCA-130 Fault-Alarm equipment[3] used with the MM-600-6 microwave equipment.

The supervisor at a manned station must be able to monitor the status of a number of functions at each remote station within his sector, and be able to command certain functions at specified remote stations.

For convenience of operation, the system is divided into a number of groups or blocks of stations, each manned station being allocated supervision of certain blocks. Information on the status of the reporting functions is transmitted from every remote station in both directions of the radio transmission path; thus, information is received by at least two manned stations. One of these stations normally monitors the data and in case of emergency the other station may monitor and control on a fall-back basis. At the remote station, the functions to be monitored are, typically: *receivers, transmitters, illegal entry, tower light, fuel,* and *alternator output.* Minor remote stations (through repeaters) report on the status of 24 functions, while major remote stations (terminals) report on 60 functions. A *local* lamp display is provided at each remote station for the convenience of the maintenance personnel.

The supervisory station is provided with both visual and audible alarm indications. Receipt and decoding of fault data by the manned station causes the alarm annunciator on the *status display* to turn on a flashing lamp and sound an audible alarm. The operator may depress an *acknowledge* switch to disable the audible alarm and cause the lamp to glow continuously. This visual condition remains until the fault at the remote station is cleared and a complete no-fault report is obtained from the remote station. In the event that a subsequent alarm occurs at the same remote station before the first one clears, the same sequence of audible alarm and flashing lamp will again take place.

Error indications are provided for each of the remote stations, recording loss of transmission or a transient code error; in this case, a special signal is generated causing the *status display error* lamp to go *on* and the alarm to sound. The audible alarm may be disabled as explained earlier and the error lamp automatically extinguished upon receipt of message from that station. When the operator at the status display is alerted to a fault from a remote station, he may switch a common *data display* unit to that station's fault-data signals. The data display is continuously updated according to the messages received from the remote stations and is automatically retained in event of loss of transmission. Indicator equipment contains a lamp display which reads out the station's total message, one lamp being provided for each function reported.

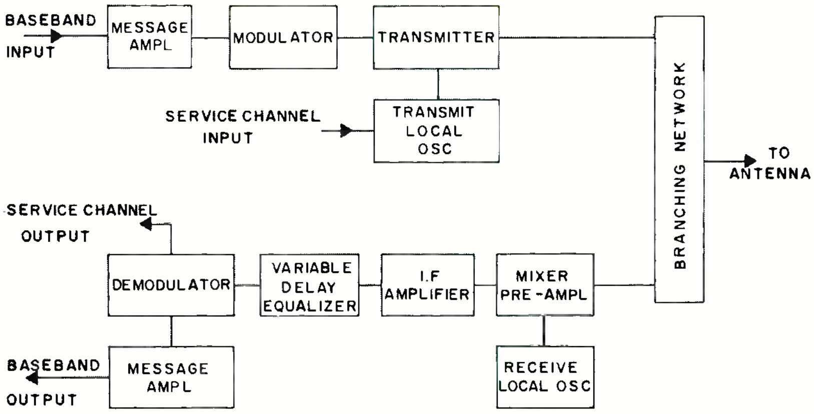

Fig. 4—A basic two-way radio terminal.

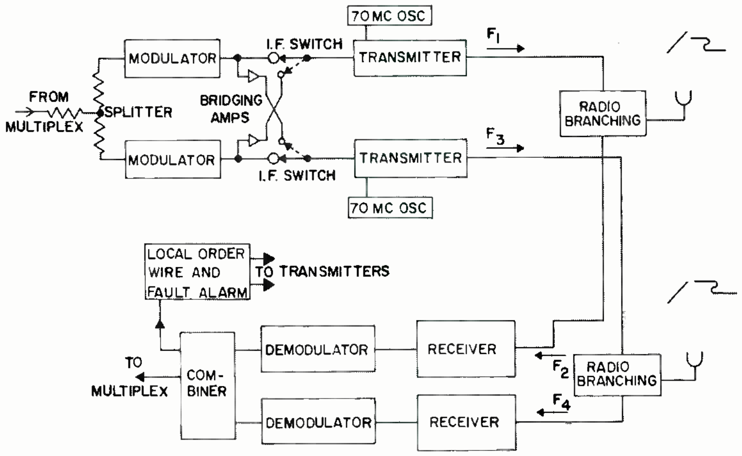

Fig. 5—A two-way diversity terminal with 100-percent fall-back provided.

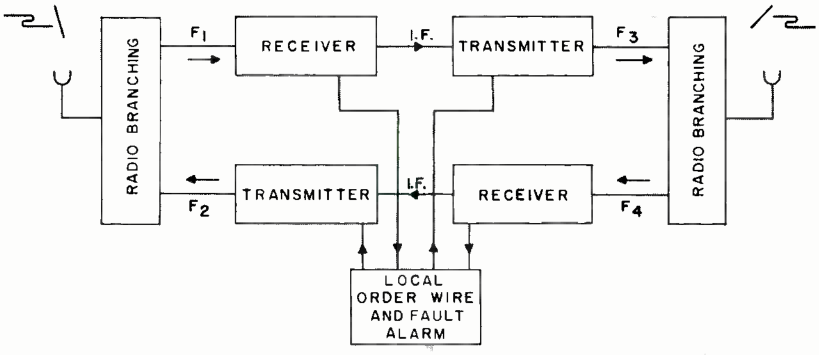

Fig. 6—A basic two-way heterodyne repeater.

**R. F. PRIVETT** graduated from King's College, London University, England, in 1945 with B. Sc. in Physics. In 1951 he obtained the M. Sc. Mathematics. He then joined the Research Laboratories of the General Electric Company, Wembley, Middlesex where he worked on IF amplifiers, frequency modulators, TE$_{01}$ propagation in circular waveguides, and magnetron moding. At the Stanmore Labs of G.E.C. he worked on a missile antenna system. In 1953, Mr. Privett joined the Canadian Marconi Company, Montreal, where he designed units for the "Mid-Canada Line" transcontinental communications system. Then, in 1956 he joined RCA Camden and assisted in the system planning of the MM-600-2. He developed the new antenna concept employed in this system. In 1960 he was responsible for the design of the MM-600-6 supplied to Western Union for their transcontinental microwave network. He is now engaged in the design of a totally solid-state microwave equipment called the CW-60. Mr. Privett serves on the EIA Committee TR-4.2 (TV Relays). He holds four patents.

**E. J. FORBES** received his BSEE at the University of Manitoba, Winnipeg in 1950. Shortly thereafter, he became Group Head, RF Development Unit, Microwave Engineering Section, Canadian G.E. Co. In 1953, he joined the RCA Victor Division, Camden, where he engaged in advanced development of microwave communications circuits, 6000-Mc travelling wave tube applications in particular. During the 1954-56 period he studied tropospheric scatter propagation at UHF and SHF. Until 1960, Mr. Forbes concentrated on the development of microwave communications equipment for long-distance radio-relay service at 2000 and 6000 Mc; he specialized on travelling-wave-tube applications and liaison between tube and equipment development groups. From 1960 to 1961 his responsibilities included the MM-600-6A6 transmitter design and determination of specifications for branching networks, waveguide components, and special power supplies. In 1961, he was promoted to Engineering Leader, assuming responsibility for the MM-600-A6 equipment. Mr. Forbes is a member of the IRE.

In addition to the monitoring circuits described, the supervisory station is able to control eighteen functions at a remote station. This command facility allows remote operation of equipment (such as diesel power sources) and must be infallible, since an error could be catastrophic. Such reliability is assured at the remote station by bit-by-bit comparison of two initial data messages before actuation by a third.

## RADIO SYSTEM PERFORMANCE

Field tests on initial message modulation sections are presently underway. The result of 600 voice-channel white-noise intermodulation measurements indicates a margin of about 2 db over the CCIR allocation of 3 picowatts/kilometer. This performance is achieved without taking advantage of baseband pre-emphasis, which would afford at least 3-db improvement of intermodulation characteristics.

## THE FUTURE

Communications systems are often loaded to capacity soon after installation and may need expansion. Extensions are likely to be added. At the same time, performance requirements will become more severe. In addition to the usual radio-equipment improvements, better antennas, feeders, and test equipments are required. Consequently, the microwave industry is forced to tighten its tolerances another notch. RCA is developing improved equipments to be ready for the new tasks.

## ACKNOWLEDGMENTS

We wish to acknowledge the dedicated efforts of the team of engineers and many co-workers that participated in the planning and successful execution of this program. Credit is due H. S. Wilson for supplying information on *Project Administration* and I. A. Fairnington for the writeup on *Fault-Alarm Facilities*.

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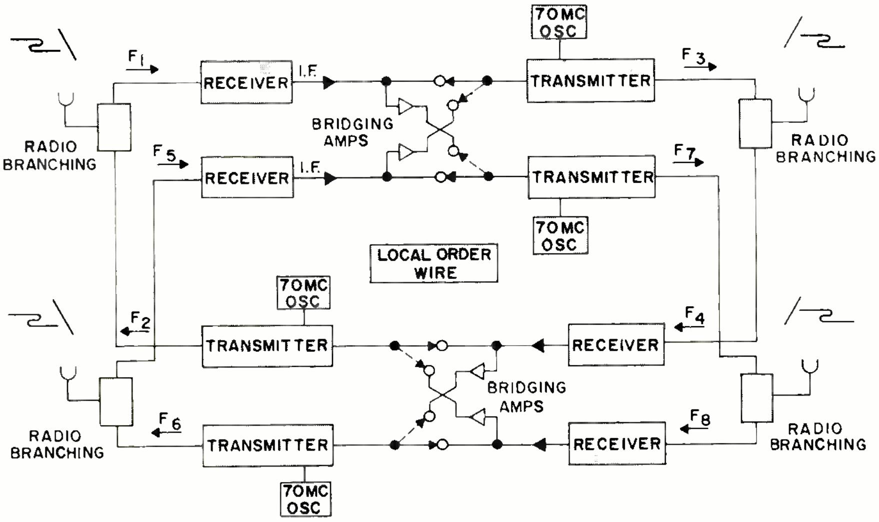

Fig. 7—A two-way diversity repeater in which automatic switching is shown.

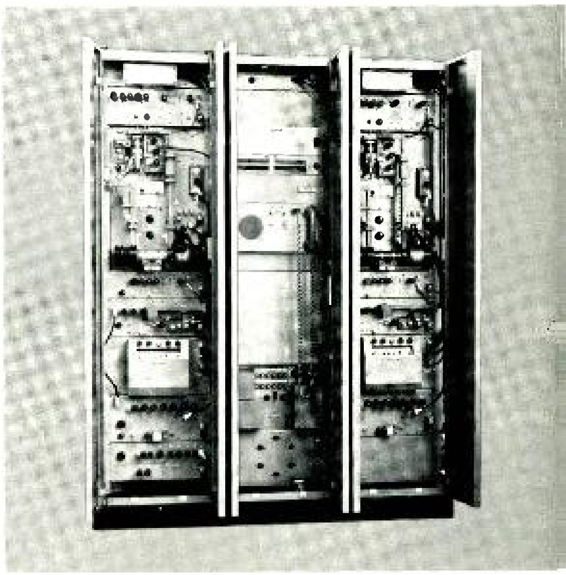

Fig. 8—The MM-600-6 two-way repeater equipment.

# Engineering and Research NOTES

## BRIEF TECHNICAL PAPERS OF CURRENT INTEREST

### Some Critical Tunnel Diode Parameters in Narrow Band Amplifier Applications

*by* S. Kallus, C. A. Renton, and A. Newton
*Systems Laboratory, Surface Communications Division, DEP, New York, N. Y.*

It was of interest to consider the tunnel diode amplifier in a communications receiver because of its relative insensitivity to radiation and variations in other ambient conditions. One of the fundamental problems encountered was to restrict the bandwidth by circuits external to the tunnel diode and still retain stability. Since tunnel-diode amplifiers have a fixed gain-bandwidth product[1], the bandwidth can be reduced without such external circuits; but, the gain of such a narrowband amplifier would increase to the point of unstable operation even with components of close tolerance.

The circuit used to band-limit the amplifier can present either a high or low impedance outside the band. Recalling the stability conditions[2] of a simple amplifier:

$$R < \frac{1}{|g|} \qquad\qquad R < \frac{L|g|}{C}$$

*Condition 1* — *Condition 2*

Where $R$ = the total resistive load on the tunnel diode, $L$ = the series inductance of the tunnel diode plus the lead inductance of the connection to the load. $C$ = the shunt capacitance of the tunnel diode, and $g$ = the negative conductance of the tunnel diode.

Condition 1 indicates the need for a circuit that presents a low impedance outside the band, such as a parallel tuned tank. In this case, the tank becomes a short circuit at high frequencies and $R$ then becomes $r_s$, the *spreading resistance* of the tunnel diode. For tunnel diodes having the values of $L$ and $C$ usually encountered, condition 2 is not fulfilled when $R = r_s$ even for the lowest values of $L$ which can be achieved, and the amplifier will be unstable (*short-circuit unstable*).

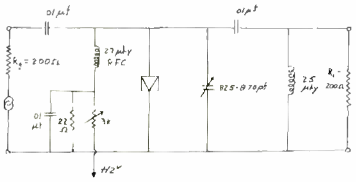

Fig. 1—Tunnel-diode IF amplifier circuit.

To avoid this, it is clear from condition 1 that either $r_s$ can be artificially increased by adding a resistance in series with the tunnel diode, or $C$ can be increased. The former solution suffers from the disadvantage that the dynamic range of the amplifier is decreased. The latter solution requires special tunnel diodes, since capacitance must be increased at the diode junction and not externally. This has been implemented with a diode supplied by W. deVersterre, of the Semiconductor and Materials Division, Somerville, N. J., having a shunt capacitance of 120 pf and a negative resistance of 125 ohms, in the circuit configuration shown in Fig. 1. This amplifier had a stable gain of 14 db and a 3 —db bandwidth of 100 kc at a center frequency of 10.7 Mc.

In summary then, a simple narrow-band tunnel-diode amplifier has been made to operate at a frequency far below the cut-off frequency of the diode by using a *short-circuit stable* tunnel diode, achieved by its large shunt capacitance.

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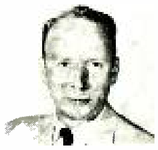
### Improved Bandwidth Measurement Technique for Vidicons



*by* J. Pirkle, *Astro-Electronics Division, DEP, Princeton, N. J.*

Of the various methods commonly employed in measuring the bandwidth of a vidicon camera, there is much to be desired from the standpoint of convenience and/or accuracy. This paper describes a method which has been found to be *both convenient and accurate.*

In normal operation, the vidicon mesh is at AC ground potential and is therefore in parallel with the target load. If an impedance $Z$ is assumed for the load, the transfer circuit may be shown as Fig. 1, for which:

$$V_o = \frac{i(s)Z}{j\omega c_t Z + 1} \tag{1}$$

Where: $V_o$ = target signal voltage, $i(s)$ = target signal current, $c_t$ = target-to-mesh capacity, and $Z$ = target load.

Conventionally, bandwidth is measured by the substitution of a constant current signal source for $i(s)$. However, the application of this source to the load invariably disturbs stray capacity, thereby modifying the results.

An alternate method is to connect a voltage signal source at $c_t$. This method isolates the load from the source. If a test signal voltage $V_m$ is applied to the mesh (with the socket removed), the transfer circuit becomes Fig. 2, for which:

$$V_o = \frac{V_m j\omega c_t Z}{jw_{ct}Z + 1} \tag{2}$$

Equating Eq. 1 to Eq. 2 for the required function of $V_m$ to simulate $i(s)$ and solving:

$$V_o = \frac{i(s)}{j\omega c_t} \tag{3}$$

From Eq. 3, if $i(s)$ is constant, $V_m$ must vary inversely with frequency. If $V_m$ is derived across the condenser of a series RC circuit from a voltage signal source $V_g$, then:

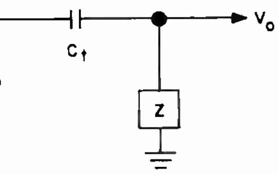
$$V_m = \frac{V_g}{j\omega RC + 1} \approx \frac{V_g}{j\omega RC} \qquad \left(\text{for } \omega > \frac{4}{RC}\right) \tag{4}$$

Substituting Eq. 4 into Eq. 3 and rearranging:

$$i(s) = V_g \frac{c_t}{RC} \tag{5}$$

Thus, a true constant-current signal source can be simulated by

Fig. 2—Alternate transfer circuit.



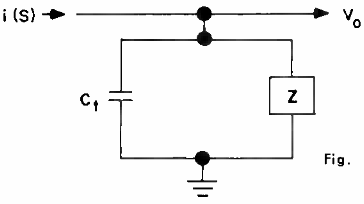


Fig. 1—Normal transfer circuit.

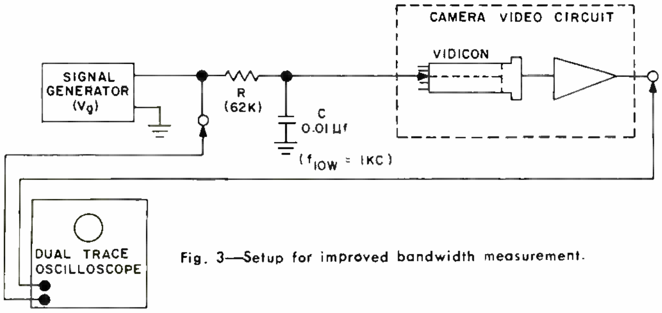


Fig. 3—Setup for improved bandwidth measurement.

utilizing the target-to-mesh interelectrode capacitance for signal insertion. Appropriate connections for this measurement are shown in Fig. 3. Assuming 3pf for $c_t$, then $i(s)$ $(m\mu a) = 5\,V_g$.

## Insulated-Gate Field-Effect Transistor for Integrated Circuits


*by* F. P. Heiman and S. R. Hofstein, *RCA Laboratories, Princeton, N. J.*

Some theoretical characteristics of the insulated-gated field-effect transistor have been investigated and the results compared with experimental units recently fabricated. These units consist of a control electrode insulated (by an oxide film) from a thin conducting channel in the surface of a silicon substrate, as compared to the conventional reverse-biased p-n junction unipolar-transistor gate.

An insulated-type gate yields several important advantages: 1) Transistors may be fabricated in which the mechanism of control is either depletion of channel charge, enhancement of channel charge, or a combination of both, providing freedom in circuit design. 2) The continuous transfer characteristic from the negative gate-bias region to the positive bias region allows operation at zero bias. 3) The oxide thickness provides a new design parameter; the thicker oxide units operate at higher speed and power level. 4) Gate leakage current is extremely low; time-constant measurements yield an input resistance of $10^{13}$ to $10^{16}$ ohms.

Units fabricated to date have the following typical characteristics: *input impedance*, 7pf, $10^{15}$ ohms; *Transconductance*, 2800 $\mu$mhos; *cut-off bias*, 8 volts (depletion unit); *rise time*, 14 nsec (10% to 90%).

The planar construction of these zero-junction devices, coupled with their highly uniform characteristics, have yielded *great promise for integrated circuit applications.* Progress is being made toward integrating these elements into large-scale logic arrays on a single-crystal semiconductor substrate.

*Acknowledgement:* The research reported here has been sponsored by the Electronics Research Directorate of the Air Force Cambridge Research Laboratories, Office of Aerospace Research (USAF), Bedford, Massachusetts, under Contract numbers AF19(604)-8040 and AF19(604)-8836.

[Editor's Note: *A full paper on this new development is under preparation for a future issue.*]

## A Light Source Modulated at Microwave Frequencies


*by* J. I. Pankove and J. E. Berkeyheiser, *RCA Laboratories, Princeton, N. J.*

When a GaAs p-n junction is biased in the forward direction, radiative band-to-band recombination is observed.[1] Since minority-carrier lifetimes of the order of $10^{-10}$ second are readily obtained in GaAs, one may expect that the recombination radiation can be modulated at gigacycle rates. This Note reports a verification that efficient generation of light modulated at microwave frequencies is possible.

The current through a GaAs diode increases very rapidly when it is forward-biased with an increasing voltage nearly equal to the energy gap (about 1.5 volts). Under this bias condition, the current consists of tunnel-assisted radiative band-to-band recombination in the space charge region of the $p_n$ junction.[2] This radiation occurs in a narrow spectral band in the near infrared (0.84$\mu$ at 77°K). The intensity of the light output first increases very rapidly (more than linearly) with current, and then linearly. In the linear range, the process is extremely efficient. A quantum efficiency of 0.50 to 1.00 photons/electron has been obtained. However, with the geometry used in our experiment, only about 1% of the radiation comes out of the specimen. The over-all power efficiency of the light source is also somewhat reduced by a small ohmic loss due to the internal resistance of the diode.

The following measurements were made with a diode fabricated by alloying a tin dot to p-type GaAs having a hole concentration of 2.5 x $10^{18}$ cm$^{-3}$. The diode was mounted in series with a 50-ohm resistor at the end of a 50-ohm coaxial cable connected to a signal generator. The diode end of the cable was inserted in a Dewar filled with liquid nitrogen (Fig. 1). The radiation was collected through the two windows of the Dewar by a lens and focussed onto a photomultiplier (RCA 7102) having an S-1 spectral response. Fig. 2 shows the detection of 200-Mc modulation as displayed on a sampling oscilloscope. A DC bias was inserted in series with the generator to operate the diode in the light-emitting mode. (The noise is believed to originate in the photomultiplier.)

In its nonlinear range, the radiation from the diode is also modulated at harmonics of the driving frequency. This is illustrated in Fig. 3, where the upper curve *d* is a 6-Mc driving signal, and the lower curve *c* is the photomultiplier output. Curve *a* is the zero level for the photomultiplier output. Because diode is insufficiently biased to give a linear light output, as the signal swings about the DC level (*b*), the light output is not symmetrical during the brightening and dimming half-cycles. The distortion of the driving voltage is due to the changing load impedance as the diode conductance increases.

The frequency limitation of our measurements is due to the transit time dispersion of electrons in the photomultiplier. Hence, an operating frequency of 200 Mc is not an upper limit for the diode. The *RC* limitation of this diode is of the order of 10 Gc.

As was stated above, only about 1% of the radiation leaves the specimen through the surface opposite the pn junction. This light comes out in a $2\pi$ steradian solid angle. An improvement of one to two orders of magnitude in light collection can be obtained by shaping the specimen into a Weierstrass sphere.[3] (We wish to thank G. B. Herzog for valuable suggestions.)

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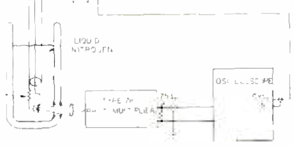


Fig. 1—Test setup.

Fig. 2—Detection of an optical signal modulated at 200 Mc as displayed by a pulse sampling oscilloscope.

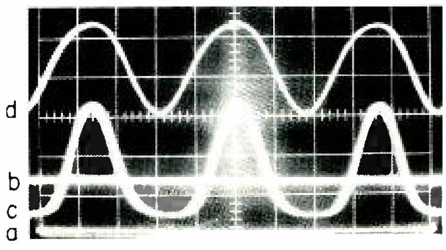
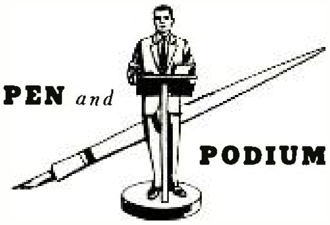


Fig. 3—Output of photomultiplier: a) no light when no current flows through diode; b) when 60-ma DC forward bias flows through diode; c) when driving signal (d) is superposed on the DC current.



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**Behavior of Gallium in Gallium Arsenide**—L. J. Vieland and T. Seidel: *Journal of Applied Physics* (Letter to the Editor), July 1962

**Reliability Considerations in the Application of Power Transistors to Consumer Products**—J. W. England and C. F. Wheatley: *IRE Transactions BTR*, July 1962

## RCA LABORATORIES

**The TFT—A New Thin-Film Transistor**—P. K. Weimer: *Proc. of the IRE*, June 1962

**Transistor Vertical Deflection Circuit Employing Transformer Coupling**—L. A. Freedman: *1962 Chicago Spring Conference on Broadcast & TV Receivers*, June 1962

**Electronics in Medicine and in Biology**—V. K. Zworykin: Introductory Report at 9th Inter. Scientific Congress on Electronics, Rome, Italy, June 18, 1962

**Measured Values of Ultra-Low Noise TWT Noise Parameters**—J. M. Hammer: 20th Annual Conference on Electron Dev. Res., Minneapolis, Minn., June 1962

**Low Noise Traveling Wave Tube Using a Plasma Cathode**—A. L. Eichenbaum: 20th Annual Conference on Electron Dev. Res., University of Minn., June 27-29, 1962

**Steady-State Noise Spectra of a Drifting Maxwellian Beam**—S. Bloom, B. Vural: 20th Annual Conference on Electron Dev. Res., University of Minn., June 27-29, 1962

**High Speed Tunnel Diode Logic Circuits**—B. J. Lechner: 9th Annual Symposium on Computers and Data Processing, Estes Park, Colo., June 27, 1962

**Optical Maser Action in CaWo4:Er$^{3+}$"**—Z. J. Kiss, R. C. Duncan, Jr.: *Proceedings of the IRE*, June 1962

**Pulsed and Continuous Optical Maser Action in CaF$_2$:Dy$^{2+}$"**—Z. J. Kiss, R. C. Duncan, Jr.: *Proceedings of the IRE*, June 1962

**Optical Maser Action in CaF$_2$:Tm$^{2+}$"**—Z. J. Kiss, R. C. Duncan, Jr.: *Proceedings of the IRE*, June 1962

**Thermal Conductivity of Semiconductors at High Temperature**—B. Abeles, G. D. Cody, D. S. Beers: International Conference on Physics of Semiconductors, Univ. of Exeter, England, July 1962

**Experimental Tunnel Diode Electromechanical Transducer Elements and Their Use in Tunnel Diode Microphones**—E. S. Rogers: *Journal of Acoustical Society of America*, July 1962

**Pair Production by Low Energy Electrons**—W. E. Spicer: International Conference on Semiconductors, Exeter, England, July 1962

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# DATES *and* DEADLINES

Professional Meetings and Calls for Papers

## Meetings

**Nov. 1-2, 1962:** 6th Natl. Conf. on Product Engineering & Production, IRE-PGPEP; Jack Tar Hotel, San Francisco, Calif. *Prog. Info.:* G. F. Reyling, Varian Associates, 611 Hansen Way, Palo Alto, Calif.

**Nov. 4-7, 1962:** 15th Ann. Conf. on Engineering in Biology and Medicine, IRE, AIEE, ISA; Conrad Hilton Hotel, Chicago, Ill. *Prog. Info.:* D. A. Holaday, P.O. Box 1475, Evanston, Ill.

**Nov. 5-7, 1962:** Nerem (Northeast Electronics Research & Engineering Mtg.), IRE; Commonwealth Armory & Somerset Hotel, Boston, Mass. *Prog. Info.:* I. Goldstein, Raytheon Co., Box 555, Hartwell Rd., Bedford, Mass.

**Nov. 7-9, 1962:** 22nd Natl. Mtg. Operations Research Soc. of America, ORSA, Sheraton Hotel, Phila., Pa. *Prog. Info.:* J. D. Kettelle, Jr., Kettelle & Wagner, 1770 Lancaster Ave., Paoli, Penna.

**Nov. 12-14, 1962:** Radio Fall Mtg., IRE-PGBTR, RQC, ED, EIA, King Edward Hotel, Toronto, Ontario, Canada. *Prog. Info.:* Virgil M. Graham, EIA Eng. Dept., 11 W. 42nd St., New York 36, N.Y.

**Nov. 12-15, 1962:** 8th Ann. Conf. on Magnetism & Magnetic Materials, IRE-PGMTT, AIEE, AIP; Penn-Sheraton, Pittsburgh, Pa. *Prog. Info.:* G. W. Weiner, Westinghouse Elec. Corp. Res. Labs. Churchill Bor., Pitts. 35, Pa.

**Nov. 16-17, 1962:** 2nd Canadian IRE Symp. on Communications: Queen Elizabeth Hotel, Montreal, P.Q., Canada. *Prog. Info.:* A. B. Oxley, Canadair Ltd., Box 6087, Montreal, P.Q., Canada.

**Nov. 19-20, 1962:** Maecon (Mid-America Electronics Conf.); Hotel Continental, Kansas City, Mo. *Prog. Info.:* Dr. John Warfield, Dept. of E.E., Univ. of Kansas, Lawrence, Kansas.

**Nov. 25-30, 1962:** 1962 ASME Winter Ann. Mtg., Statler Hilton, NYC. *Prog. Info.:* The American Soc. of Mechanical Engrs. United Engineering Center, 345 E. 47th St., New York 17, N.Y.

**Nov. 28-30, 1962:** 1962 Ultrasonics Symp., IRE-PGUE; Columbia Univ., New York City. *Prog. Info.:* R. N. Thurston, Bell Tel. Labs., Murray Hill, N.J.

**Dec. 4-6, 1962:** FJCC (Fall Joint Computer Conf.), AFIPS, PGEC, AIEE, ACM; Sheraton Hotel, Philadelphia, Pa. *Prog. Info.:* E. G. Clark, Burroughs Research Center, Box 843, Paoli, Pa.

**Dec. 6-7, 1962:** PGVC Conf. (PG on Vehicular Communications); Disneyland Motel, Los Angeles, Calif. *Prog. Info.:* W. J. Weisz, Motorola, Inc., Comm. Div. 4545 W. Augusta Blvd., Chicago 51, Ill.

**Jan. 8-10, 1963:** Millimeter and Submillimeter Conf., IRE; Cherry Plaza Hotel, Orlando, Florida. *Prog. Info.:* J. W. Dees, Martin Co., P.O. Box 5837, MP-172, Orlando, Florida.

**Jan. 21-24, 1963:** 9th Natl. Symp. on Reliability & Quality Control, IRE-PGRQC, AIEE, ASQC, EIA; Sheraton Palace Hotel, San Francisco, Calif. *Prog. Info.:* L. W. Ball, Boeing Co. P.O. Box 3707, Seattle 24, Wash.

**Jan. 27-Feb. 1, 1963:** 1963 AIEE Winter General Mtg.: Hotel Statler-Hilton & Hotel New Yorker, New York, N.Y. *Prog. Info.:* E. C. Day, Ass't Secy., TOD, AIEE, 345 E. 47th St., New York 17, N.Y.

**Jan. 30-Feb. 1, 1963:** 4th Winter Convention on Military Electronics, IRE-PGMIL; Ambassador Hotel, Los Angeles, Calif. *Prog. Info.:* IRE L.A. Office, 1435 La Cienega Blvd., Los Angeles, Calif.

## Calls for Papers

**Jan. 24-28, 1963:** 69th Ann. Mtg. American Mathematical Soc. and The Mathematical Assn. of America, Berkeley, Calif. *DEADLINE:* Abstracts, **11/23/62,** to American Mathematical Soc., 190 Hope St., Providence 6, R.I.

**Feb. 20-22, 1963:** Intl. Solid State Circuits Conf., IRE-PGCT, AIEE, Univ. of Penn., Sheraton Hotel & Univ. of Penn. Phila., Pa. *DEADLINE:* 300-500 wd summary and 35-wd abstract, **11/1/62,** to A. K. Rapp, Philco Scientific Lab. Blue Bell, Pa.

**March 25-28, 1963:** IRE Intl. Conv., Coliseum and Waldorf-Astoria Hotel, New York. *DEADLINE:* **10/19/62,** to Dr. D. B. Sinclair, IRE Headquarters, 1 E. 79 St., New York 21, N.Y.

**April 14-18, 1963:** The Electrochemical Society, Inc., Penn Sheraton Hotel, Pittsburgh, Pa. *DEADLINE:* Triplicate copies of 75-wd abstract and 500-1000-wd abstract, **12/14/62,** to Society Headquarters, 30 E. 42nd St., New York, N.Y.

**April 17-19, 1963:** Intl. Special Tech. Conf. on Non-Linear Magnetics (Intermag), IRE-PGEC, PGIE, AIEE; Shoreham Hotel, Washington, D.C. *DEADLINE:* 200-wd abstracts **11/5/62,** to J. J. Suozzi, BTL Labs, Whippany, N.J.

**May 13-15, 1963:** Naecon (Natl. Aerospace Electronics Conf.), IRE-PGANE, Dayton Sect.; Dayton, O. *DEADLINE:* Approx. **12/15/62.** For Info.: IRE Dayton Office, 1414 E. 3rd St., Dayton, Ohio.

**May 20-22, 1963:** Natl. Symp. on Microwave Theory & Techniques, IRE-PBMTT; Miramar Hotel, Santa Monica, Calif. *DEADLINE:* 100-wd abstract, 1000-wd summary, in duplicate, with title, **1/5/63,** to Dr. Irving Kaufman, Space Tech. Labs, Inc., Space Pk., Redondo Beach, Calif.

**May 21-23, 1963:** Spring Joint Computer Conf., (AFIPS, PGEC, AIEE, AIM); Cobo Hall, Detroit, Mich. *DEADLINE:* Approx. **11/10/62.** For Info.: E. C. Johnson, Bendix Corp., Res. Labs Div., Southfield, Mich.

**June 4-5, 1963:** 5th Natl. Radio Frequency Interference Symposium, PGRFI; Philadelphia, Pa. *DEADLINE:* Approx. **1/1/63.** For info.: IRE, 1 E. 79th St., New York 21, N.Y.

**June 11-13, 1963:** Natl. Symp. on Space Electronics & Telemetry, IRE-PGSET; Los Angeles, Calif. *DEADLINE:* Approx. **12/15/62.** For info.: J. R. Kauke, Kauke & Co., 1632 Euclid St., Santa Monica, Calif.

**Aug. 4-9, 1963:** International Conf. on Aerospace Support Systems, Washington, D.C. *DEADLINE:* 250-wd abstract, **12/3/62,** paper **2/18/63,** to Technical Sessions Committee, Technical Papers, P.O. Box 6635, Washington 9, D.C.; *Further info.:* D. Dobson, ACC, RCA, Burlington, Mass.

**Aug. 20-23, 1963:** Wescon (Western Elec. Show & Conf.), IRE, WEMA; Cow Palace, San Francisco, Calif. *DEADLINE:* Approx. **4/15/63.** For info.: Wescon, 1435 La Cienega Blvd., Los Angeles, Calif.

**Sept. 18-19, 1963:** 12th Ann. Industrial Electronics Symposium, IRE-PGIE, AIEE, ISA; Mich. State Univ., E. Lansing, Mich. *DEADLINE:* Approx. **5/1/63.** For info.: L. J. Giacaletto, Mich., State Univ., EE Dept., E. Lansing, Mich.

**Sept. 30-Oct. 1-2, 1963:** Canadian Electronics Conf., IRE; Toronto, Ontario, Canada. *DEADLINE:* Approx. **4/1/63.** For info.: IRE; Canadian Elec., Conf., 1819 Yonge St., Toronto 7, Canada.

**Oct. 7-9, 1963:** 9th Natl. Communications Symposium, IRE-PGCS; Utica, New York. *DEADLINE:* Approx. **6/1/63.** For info.: IRE, 1 E. 79th St., New York 21, N.Y.

**Oct. 15-18, 1963:** Intl. Symp. on Space Phenomena & Measurement, IRE; Statler-Hilton, Detroit, Mich. *DEADLINE:* 300-500-wd summary and 35-wd abstract, **11/1/62,** to A. K. Rapp, Philco Scientific Laboratory, Blue Bell, Pa.

**Oct. 28-30, 1963:** Natl. Electronics Conf., IRE, AIEE, et al.; McCormick Pl., Chicago, Ill. *DEADLINE:* Approx. **6/1/63.** For info.: Natl. Elec. Conf., 228 No. LaSalle St., Chicago, Ill.

**Oct. 31-Nov. 1, 1963:** 1963 Electron Devices Mtg., IRE-PGED; Sheraton Park Hotel, Wash., D.C. *DEADLINE:* Approx. **8/1/63.** For info.: IRE Headquarters, 1 E. 79th St., New York 21, N.Y.

**Nov. 4-6, 1963:** Nerem (Northeast Research and Eng. Meeting) IRE; Boston, Mass. *DEADLINE:* Approx. **6/1/63.** For info.: NEREM-IRE; Boston Office, 313 Washington St., Newton, Mass.

**Nov. 10-14, 1963.** 9th Ann. Conf. on Magnetism and Magnetic Materials, IRE-PGMTT, AIEE, AIP; Chalfonte-Haddon Hall, Atlantic City, N.J. *DEADLINE:* Approx. **8/15/63.** For info.: IRE Headquarters, 1 E. 79th St., New York 21, N.Y.

**Nov. 12-14, 1963:** Fall Joint Computer Conf. (IRE-AFIPS, PGEC, AIEE, ACM); Ambassador Hotel, Los Angeles, Calif. *DEADLINE:* Approx. **6/1/63.** For info.: IRE Headquarters, 1 E. 79th St., New York 21, N.Y.

Be sure DEADLINES are met — consult your Technical Publications Administrator for lead time needed to obtain required RCA approvals.

**Evidence for the Existence of High Concentrations of Lattice Defects in GaAs**—J. Blanc, R. H. Bube, L. R. Weisberg: International Conference on the Physics of Semiconductors Univ. of Exeter, Exeter, England, July 11-12, 1962

**The Flexode—An Adaptive Semiconductor Device**—J. O. Kessler: IRE Device Meeting, Univ. of N. H., Durham, N. H., July 7, 1962

**Further Aspects of Negative Mass Cyclotron Resonance Work**—G. C. Dousmanis, B. W. Faughnan, R. M. Josephs, International Conference on the Physics of Semiconductors, Univ. of Exeter, Exeter, England, July 16-20, 1962

**Reflectivity Measurements on InSb-$In_2Te_3$ and InAs-$In_2Te_3$ Alloys and on Pure InSb, InAs and $In_2Te_3$**—D. L. Greenaway: Semiconductor Conference International, Exeter, England, July 11-12, 1962, *Proceedings* of Conference.

**Effect of Disorder on the Transition Temperature of Niobium Stannide**—J. J. Hanak, J. G. White, G. D. Cody: American Physical Society Meeting, Seattle, Wash., July 27-29, 1962

**Thermal Effect of Resistive Current Contacts on the Quenching Current of Niobium Stannide**—J. J. Hanak: American Physical Society Meeting, Seattle, Wash., July 27-29, 1962

**A Light Source Modulated at Microwave Frequencies**—J. I. Pankove, J. E. Berkeyheiser: *Proceedings of the IRE-Letter to the Editor.* Semi-conductor Device Conference, Durham, N. H., July 1962

**Kinks in the Current-Voltage Characteristic of Heterojunction Diodes**—S. S. Perlman, D. Feucht, R. M. Williams: 1962 IRE-AIEE Solid State Device Research Conference, Univ. of N. H., Durham, N. H., July 10, 1962

## ELECTRONIC DATA PROCESSING

**The Design of a Magnetic Tape Transport for Very High Timing Accuracy**—G. V. Jacoby: AIEE, Denver, Colo., June 19, 1962

**High Speed Logic Circuits Using Tunnel Diodes**—R. H. Bergman, M. Cooperman and H. Ur: *RCA Review*, June 1962

**Outer Space and the Inner Man**—A Challenge to Education—H. N. Morris: Southern States Work Conference, Daytona Beach, Fla., June 7, 1962

**Parameter Variations in Control Systems**—H. Ur: Polytechnic Inst. of Brooklyn, N. Y.

**The Design of a Sense Amplifier for a Thin Film Memory**—T. R. Mayhew: Master's Degree, Univ. of Penna., July 1962

## BROADCAST AND COMMUNICATIONS PRODUCTS DIV.

**Noise and Propagation Limits for Optimum Signal Levels in Microwave Links**—O. A. Bonanni: Thesis MSEE Degree, Univ. of Pa.

**Small Boat Electronics—Present and Future**—N. L. Barlow: *Ensign*, July-August 1962 Issue

**Design Aspects of the Cold Stage for EMU-3 Series Electron Microscopes**—J. W. Coleman and A. J. Catlile: *RCA Scientific Instruments News*, Vol. III, No. 1

**Air Bearings Improve Video Headwheel Panels**—F. M. Johnson: *Broadcast News*, May 1962

**Image Orthicon Camera Operating Techniques, Present and Future**—H. N. Kozanowski: *Broadcast News*, May 1962

**The BTA-1R1—A New 1 Km AM Broadcast Transmitter**—L. S. Lappin: *Broadcast News*, May 1962

**Sense Antenna Operation Applied to Small Craft Direction Finders**—E. W. Mahland: *Electrical Engineering*

**Automatically Stabilized True View Radar**—C. Moore: *Teknisk Ukelblad*, Norway, June 1962

**Comprehension and Limitations of Radar**—C. E. Moore: School for Towboat Masters, Illinois

**A Varidirectional Condenser Microphone**—M. Rettinger: Society of Motion Picture & TV Engineers, 91st Convention, L. A., Calif.

**Stability Criteria or Television Pickup Tubes**—K. Sadashige: *SMPTE Journal*, June 1962

**A Stereophonic Pickup for Broadcast Use**—J. R. Sank: *Broadcast News*, May 1962

**New RCA FM Multiplex Monitor**—H. J. Shay: *Broadcast News*, May 1962

## DEFENSE ELECTRONIC PRODUCTS

**Plasma Physics—Old Laws and New Forms**—Dr. J. Vollmer: Penna. State & Temple Univ. Sigma Pi Sigma Group (National Physics Honor Soc.), Temple Univ., March 31, 1962

**Neural Networks**—T. B. Martin: IRE, Orlando, Fla., March 14, 1962

**Development and Application of Fiber Optics Techniques to Precision Measuring Devices, Transducers and Automatic Control Systems**—E. Grim: 1962 Electronic Components Conference, Wash., D. C., May 8-10, 1962

**Sequential Decoding**—G. Hennessey: Phila. Chapter IRE PG Communication Systems, May 21, 1962

**Information Systems and the Planning Process**—Dr. D. C. Beaumariage: Delaware Valley Chapter of the Institute of Management Sciences, May 29, 1962

**Mathematical Analysis of 1-Shot Redundant Systems Solving the Problem with Matrix Algebra**—G. Weinstock: 8th National Symposium on Reliability and Quality Control

**Nuclear Burst Phenomena**—J. R. Parker: IRE, St. Joseph Univ., April 17, 1962

**Superconductivity—Theory and Applications**—J. P. McEvoy: American Institute of Physics Student Sect., Iona College, May 11, 1962

**Plasma Power**—Dr. J. Vollmer: S. J. Section of the American Chemical Soc.

**Plasmas, Microwaves and Space**—Dr. J. Vollmer: Frankford Research Society, Frankford Arsenal, Phila.

**The Logic Design of the FC-4100 Data-Processing System**—A. Schwartz: San Fernando Valley Chapter of the Assoc. for Computing Machinery Seminar, June 13, 1962

**Film Recording and Reproduction**—M. C. Batsel and G. L. Dimmick: *Proceedings of the IRE*, May 1962

**New Design for Miniature Modules**—A. C. Corrado and J. W. Smiley: *Electronic Equipment Engineering*, June 1962

**An Accordion Communication System for Mobile Use**—J. Klapper, B. Rabinovici: 6th MIL-E-CON, Wash., D. C., June 27, 1962

**Tolerances in Coaxial Low Pass Filters**—R. M. Kurzrok: *Electronics*, June 29, 1962

**White Room at Cambridge**—C. N. Vallette: *Tooling and Production*, July 1962

**Comparison of Analog-to-Digital Conversion Techniques**—S. Wald: *Electronic Design*, August 2, 1962

**Fiber Optics and Its Use in Electro-Optical Devices**—L. J. Krolak: NATO Advisory Group for Aeronautical Research and Development, Paris, France, July 9, 1962

**Field Testing at Fort Huachuca**—C. W. Fields: *Arizona Engineer & Scientist*, August 1962

**Versatile Zener Diode Array Forms High-Speed Quantizer**—J. Kolarcik: *Electronics*, August 20, 1962

**BMEWS: Its Present and Its Future in Missile and Satellite Surveillance**—S. G. Miller, A. Korbin: IRE Baltimore Sub-Section, April 9, 1962

**Multi-Target Monopulse Signal Processing for a Scanning and Tracking Radar System**—N. Hill: MIL-E-CON, Wash., D. C., June 27, 1962

**Sensing Systems for North American Defense**—C. Conner: U. S. Naval Research Co., Oak Ridge, Tenn., Jan. 24, 1962

**BMEWS—Missile Warning and Satellite Surveillance**—H. Saks: 8th Annual Radar Symposium, Univ. of Mich., June 6, 1962 and *Symposium Record.*

**Lunar Echo Boresighting for Large Aperture System**—A. Rauchwerk, W. Mehuron: Joint Thesis, Univ. of Penna.

**A Logical Framework for the Checkout Phase of Complex Systems**—H. Birnkrant: Thesis, Univ. of Penna.

**Executive Coordination Center**—R. Coyer and T. Johnston: Operations Research Society of America, Wash., D. C., May 11, 1962

**Digital Computations and Real-Time—Some Systems and Programming Considerations**—D. Mayer: Mass. Institute of Tech. Digital Computation Laboratory, May 8, 1962

**Phase-Lock Demodulation for Wideband Signals**—J. Bry: Thesis, Univ. of Penna.

**Finite Constant Time Delay Networks**—H. Saks: Thesis, Brooklyn Polytechnic Institute, Brooklyn, N. Y.

**A Family of Digital Transducers**—P. E. Brown and M. L. Feistman: Aerospace Instrumentation Symposium, Washington, D. C., May 21, 1962, Summer General Meeting AIEE, Denver, Colorado, June 19, 1962

**Instrumentation for a Nuclear Rocket**—P. E. Brown: Gordon Research Conference on Instrumentation, Aug. 6, 1962

**Performance Prediction Techniques**—W. A. Rose: Symposium on Automatic Checkout Techniques, Battelle Memorial Institute, Columbus, Ohio, Sept. 7, 1962

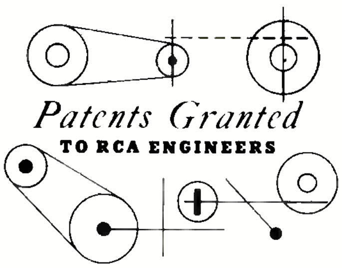
**Development and Application of Fiber Optics Techniques to Precision Measuring Devices, Transducers and Automatic Control Systems**—E. D. Grim: 1962 Electronic Components Conference, Washington, D. C., May 10, 1962

**Performance of Digital Communications Systems in an Arbitrary Fading Rate and Jamming Environments**—A. B. Glenn, G. Lieberman: IRE National Convention on Military Electronics, Washington, D. C., June 26, 1962, and IRE WESCON, Los Angeles, Calif., Aug. 24, 1962

**Estimation of Component and System Failure Rates from Test Data**—R. Mirsky: IRE National Convention on Military Electronics, Washington, D. C., June 26, 1962

**Nuclear Rocket Instrumentation**—P. E. Brown: 17th Annual Instrument Society of America Conference, New York City, Oct. 16, 1962

**Chirp Signals for Communications**—M. R. Winkler: WESCON, Los Angeles, Calif., Aug. 23, 1962



# *Patents Granted*
## TO RCA ENGINEERS

As Reported By RCA Domestic Patents, Princeton

## DEFENSE ELECTRONIC PRODUCTS

**3,037,422—Composite Photography,** June 5, 1962; H. E. Haynes

**3,039,185—Soldering Apparatus and Method,** June 19, 1962; W. L. Oates

**3,041,418—Transducers,** June 26, 1962; A. G. Lazzery

**3,041,544—Stabilized Signal Amplifier Circuits Employing Transistors,** June 26, 1962; J. E. Lindsay

**3,045,185—Repeater Station Having Diversity Reception and Full Hot Standby Means,** July 17, 1962; H. R. Mathwich

**3,046,359—Magnetic Heads,** July 24, 1962; H. R. Warren

**3,047,737—Transistor Multivibrator Circuit with Transistor Gating Means,** July 31, 1962; L. Kolodin

**3,046,334—Television Optical System,** July 24, 1962; J. H. Roe

## ELECTRON TUBE DIVISION

**3,037,533—Apparatus for Use with Automatic Grid Winding Machines,** June 5, 1962; J. A. Chase

**3,037,874—Method of Preparing Ceramic Compositions,** June 5, 1962; L. P. Garvey

**3,038,086—Radio Frequency Logic Circuits,** June 5, 1962; F. Sterzer

**3,041,127—Method of Fabricating a Cathode Ray Tube,** June 26, 1962; J. C. Turnbull

**3,041,494—High Voltage Rectifier Tube,** June 26, 1962; M. E. Lough and D. L. Curry

**3,041,495—Grid Mounts for Electron Tubes,** June 26, 1962; M. B. Knight, J. J. Thompson

**3,043,323—Bakable Ultra-High Vacuum Valve,** July 10, 1962; J. T. Mark and J. H. Gantz

**3,043,446—Apparatus for Orienting and Inserting Electrical Devices,** July 10, 1962; J. L. Beers

**3,047,757—Image Intensifier Devices,** July 31, 1962; A. A. Rutow

## RCA LABORATORIES

**3,038,073—Electrostatic Charging,** June 5, 1962; E. J. Johnson

**3,038,085—Shift-Register Utilizing Unitary Multielectrode Semiconductor Device,** June 5, 1962; J. T. Wallmark

**3,038,124—Maser,** June 5, 1962; L. E. Norton

**3,038,154—Apparatus for Meteorological Exploration,** June 5, 1962; V. K. Zworykin

**3,040,113—Thermal Power Generating System,** June 19, 1962; N. E. Lindenblad

**3,040,704—Apparatus for Developing Electrostatic Printing,** June 26, 1962; W. H. Bliss

**3,041,490—Electroluminescent Apparatus,** June 26, 1962; J. A. Rajchman

**3,042,831—Velocity Modulation Electron Discharge Devices,** July 3, 1962; N. C. Barford

**3,042,834—Electroluminescent Device,** July 3, 1962; F. H. Nicoll

**3,042,852—Semiconductor Cryistor Circuit,** July 3, 1962; M. C. Steele

**3,042,853—Semiconductor Electrical Apparatus,** July 3, 1962; M. C. Steele

**3,042,905—Memory Systems,** July 3, 1962; W. F. Kosonocky

**3,042,923—Magnetic Switching Systems for Magnetic Recording,** July 3, 1962; H. D. Crane

**3,043,961—Electroluminescent Device and circuits therefor,** July 10, 1962; B. Kazan

**3,045,141—Electron Beam Tube,** July 17, 1962; D. W. Epstein, J. W. Schwartz, F. Edelman

**3,046,335—Noise Protection Circuit for Television Receivers,** July 24, 1962; R. N. Rhodes and J. Avins

**3,046,441—Infra-red Sensitive Television Camera Systems,** July 24, 1962; H. B. DeVore

**3,046,496—Stabilized Frequency Modulated Oscillator,** July 24, 1962; B. A. Trevor

**3,046,529 — Ferroelectric Memory Systems,** July 24, 1962; G. R. Briggs

**3,047,429 — Magnetic Recording Medium Comprising Coatings of Ferrite Particles of the Molar Composition $a\mathrm{MnO} \cdot b\,\mathrm{ZnO} \cdot c\,\mathrm{Fe_2O_3}$,** July 31, 1962; A. I. Stoller and I. Gordon

**3,047,505—Magnetic Recording Media,** July 31, 1962; A. Miller

**3,047,744—Cryoelectric Circuits Employing Superconductive Contact Between Two Superconductive Elements,** July 31, 1962; J. I. Pankove

## SEMICONDUCTOR AND MATERIALS DIVISION

**3,039,962—Ferromagnetic Ferrite and Process of Preparing Same,** June 19, 1962; E. G. Fortin

**3,042,617—Magnetic Bodies and Methods of Preparation Thereof,** July 3, 1962; H. Lessoff

**3,043,777—Methods for Preparing Improved Magnetic Bodies,** July 10, 1962; H. Lessoff, R. Laird and J. D. Childress

**3,046,176 — Fabricating Semiconductor Devices,** July 24, 1962; W. A. Bosenberg

## HOME INSTRUMENTS DIV.

**3,040,298—Remote Control System,** June 19, 1962; L. P. Thomas, C. W. Hoyt and C. C. Iden

**3,046,022 — Automatic Phonographrecord Player,** July 24, 1962; R DiSabatino

## BROADCAST AND COMMUNICATIONS DIVISION

**3,041,168—Electrostatic Printing,** June 26, 1962; H. Wielicki

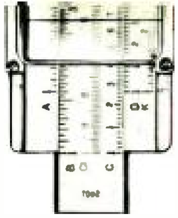
**3,041,169—Reversal Type Electrostatic Developer Powder,** June 26, 1962; H. Wielicki

## ELECTRONIC DATA PROCESSING

**3,042,867—Communication System with Compensating Means for Non-Linear Amplitude Distortions,** July 3, 1962; L. E. Thompson

**3,047,843 — Monitoring Circuits,** July 31, 1962; A. Katz and A. Rauchwerk

# *Engineering* NEWS *and* HIGHLIGHTS



## INCREASES MADE IN TUITION LOAN AND REFUND PLAN

The RCA Tuition Loan and Refund Program has been changed to provide increased financial assistance at the graduate degree level. Under the plan, RCA loans money to qualified employees to cover tuition costs for approved study courses. The loan is deducted in installments from the employee's pay, but the money is refunded upon successful completion of the course.

Previously, a maximum of $225 loan and refund per academic year existed for all study programs. Now, however, employees studying at the master's or doctor's level can receive reimbursement of $225 per school year plus 50 percent of additional tuition incurred to a maximum reimbursement of $325. To receive the maximum reimbursement of $325, the employee must incur tuition expenses, not including textbooks, laboratory fees, and other miscellaneous items, of $425 or more. No change has been made in the $225 maximum for undergraduate study.

In all cases, the individual courses or degree programs to be approved must be judged to improve the performance of the employee in his present job or to contain knowledge needed in closely related occupations.

Loans or refunds will be granted on a maximum of 6 credit hours per semester or 12 credit hours each school year, including summer sessions. Correspondence school training is permissible for employees who are not close to resident schools and for employees who travel extensively or work on rotating shifts.

## RCA EARNING FOR FIRST HALF AT ALL-TIME HIGH; PROFITS RISE

For the first half of 1962, RCA registered an all-time profit and sales record. After-tax earnings for the second quarter were 70% higher than for the same quarter of 1961. For the first six months of 1962, profits after taxes rose to $24,000,000 compared with $17,600,000 for the 1961 period—an increase of 36 percent. This was achieved on a sales record of $854,000,000 up 18 percent over the $722,000,000 volume for the same period a year ago.

Earning per common share totaled $1.32 for the first half of 1962, compared with 97 cents for the same period of 1961.

In a joint statement, RCA Board Chairman **David Sarnoff** and President **Dr. Elmer W. Engstrom** said that the profit and sales record reflected a strong growth pattern in all the principal areas of RCA's business. They added:

"We believe that if the economy maintains its present level of activity, RCA will do even better in the second half of 1962 than in the first.

"Our confidence is based on the general health of the company's operations, including the sales growth in color TV and other home instruments, the gains which continue to be chalked up by NBC, and the increased profitably of all major RCA divisions, except electronic data processing, where increased sales and rental income are bringing the Corporation closer to the goal of profitable operations.

"Sales of RCA home instruments, for the first half of the year, were the highest in the Corporation's 43-year history. Color TV continued as the pace-setter, but black-and-white TV, radios and "Victrola" phonographs also gained significantly. We are setting new monthly production records in the output of color tubes, with our facilities operating on a round-the-clock basis to meet the public and industry demands.

"The National Broadcasting Company achieved the highest sales and earnings ever scored for the half year, and the prospects appear good that this upward trend will continue."

## TELEX SERVICE WITH GHANA INAUGURATED BY RCA COMMUNICATIONS, INC.

RCA Communications, Inc., New York, has inaugurated telex service between the United States and Ghana, bringing the total number of countries served by the RCA telex network to 70. The new service permits RCA telex subscribers in New York, San Francisco, and Washington, D. C., as well as more than 55,000 subscribers to the Bell TWX and Western Union telex networks, to engage in direct office-to-office teletype conversations with their correspondents in Accra, Ghana.

## LAYTON RECEIVES NARAS AWARD

**Lewis W. Layton,** an RCA Victor Record Division employee for more than 40 years, recently was presented a "Grammy" by the National Academy of Recording Arts and Sciences for the "Best Engineering Contribution in a Classical Recording." The recording, Ravel's "Daphnis Et Chloe" by the Boston Symphony Orchestra, was named the "Best Classical Performance by an Orchestra," making it the first ever to win NARAS awards in both categories. The RCA Victor Record Division led all other record producers with 12 NARAS awards, including the two for "Daphnis Et Chloe."

## CARLTON AWARD TO D. K. BARTON

**David K. Barton,** DEP-M&SR, Moorestown, received the *M. Barry Carlton Award* at the sixth National Convention on Military Electronics in Washington.

The award, recognizes the best paper published during the past year in the *IRE Transactions on Military Electronics,* Mr. Barton's paper "The Future of Pulse Radar for Missile and Space Range Instrumentation" appeared in the October 1961 issue of that journal.—*T. G. Greene*

## NEW APPLIED RESEARCH LAB FOR SUPERCONDUCTIVE MAGNETS

Establishment of an applied research laboratory located at the RCA Laboratories, Princeton, to perfect techniques for mass-producing superconductive, niobium-tin high-field magnets has been jointly announced by **Douglas Y. Smith,** Vice President and General Manager, Electron Tube Division, and **Dr. James Hillier,** Vice President, RCA Laboratories.

**Norman S. Freedman,** former head of the Electron Tube Division's Chemical and Physical Laboratory, Harrison, N. J., will be in charge of the new laboratory, which is supported directly by ETD.

The techniques to be developed in the new lab are expected to lead to commercial output of a number of superconductive devices, in addition to magnets, by using an important new process developed by RCA Laboratories for rapid and continuous production of niobium-tin. Because of its unique value as a superconductor and because of RCA's simplified process for making it, niobium-tin is expected to open important new product possibilities for ETD. As soon as promising niobium-tin devices and the techniques for their fabrication are developed, they will be phased directly into ETD Harrison, where a pilot line for the manufacture of niobium-tin ribbon already exists.

## ARE YOU REGISTERED?

In the June-July 1962 RCA ENGINEER the editorial by **J. C. Walter,** "Registered Professional Engineers in Industry" included a list of some 230 RCA engineers who were known to possess state licenses. The Editors realized the list was incomplete, and asked that readers who were licensed (and not included in that list) send that information in. Then, in the August-September 1962 issue, an additional 66 were listed who had submitted the information. The following further additions to the roster have been received in the past few weeks. If you are licensed and have not yet informed the RCA ENGINEER, send that information to: RCA ENGINEER, 2-8, Camden, N. J.

**R. H. Pollack, SCM, PE-6191E, *Pa.***
**P. Anzalone, DEP, PE-11837, *N. J.***
**J. P. Buckley, DEP, PE-33819, *N. Y.;* PE-27938, *Ohio***
**O. L. Utt, DEP, PE-6135-E, *Pa.***
**R. S. Lorenz, DEP, EIT, *Ohio***
**K. R. Heiser, DEP, PE-8547, *Ind.***
**C. A. Steuernagel, DEP, PE-13417, *Mass.***
**D. Cohen, ETD, PE-7818, *N. J.***
**M. J. Sarullo, ETD, PE-10272, *N. J.***
**R. H. Baker, DEP, ME-9114, *Calif.;* PE-9980, *N. J.***
**G. H. Stagner, RCAC, EE-4119, *Calif.***
**H. B. Morris, RCAC, EE-4441, *Calif.***
**L. P. Schaefer, DEP, PE-7642-E, *Michigan***
**J. A. DiMauro, SCM, PE-9989, *N. J.***
**C. N. Vallette, DEP, PE-2811E, *Pa.***
**F. W. H. Wehner, DEP, PE-9674, *Texas***
**H. E. Miller, DEP, Arch-4735, *N. Y.;* PE-01844, *Pa.***
**T. A. Mullett, DEP, PE-18956, *Ohio***
**D. A. Nufer, DEP, PE-9249, *Michigan***
**W. P. Robinson, DEP, PE-707E; PE-367, *Va.***
**M. Rubin, DEP, PE-30763, *N. Y.***
**J. H. Wallie, DEP, PE-3873, *Kentucky***
**G. E. Wolfe, DEP, PE-15774, *N. Y.;* PE-7432, *N. J.***
**N. Schwarz, DEP, PE-1985, *Maine***
**D. A. Knowlton, DEP, PE-2596, *Colorado***
**P. Levi, DEP, PE-37438, *N. Y.***
**J. J. Boyle III, BCD, PE-4783-E, *Pa.***
**E. Jellinek, DEP, PE-22650, *N. Y.***

## ...PROMOTIONS...

### *to Engineering Leader and Manager*

*As reported by your Personnel Activity during the past two months. Location and new supervisor appear in parenthesis.*

**Surface Communications Division, DEP**

**B. L. McKern:** from Senior Member Tech. Staff to *Ldr., Design and Development Engrs.* (E. S. Petterson, Field Engineering and Documentation, Cambridge, Ohio)

**R. E. Owen:** from Ldr., Tech. Staff to *Sr. Eng. Scientist* (S. J. Mehlman, Mgr., Advanced Circuit Techniques, Systems Lab., N. Y.)

**S. Cascio:** to *Ldr., Design and Development Engrs.* (Chemical-Metallurgical Engineering), (P. R. Riley, Mgr., Reliability and Value Engineering, Cambridge, Ohio)

**A. C. Thompson:** to *Ldr., Design and Development Engrs.* (W. J. Connor, Mgr., Missile Systems Communications, Camden)

**W. D. Clement:** to *Ldr., Design and Development Engrs.* (V. Ziemelis, Mgr., Dyna Soar Ground Communications Engineering, Camden)

**Aerospace Communications and Controls Division, DEP**

**I. Nepo:** from Senior Project Member, Tech. Staff to *Ldr., Tech. Staff* (E. B. Galton, Reconnaissance & Surveillance Products, Burlington)

**J. C. Escude:** from Engineering Scientist, Tech. Staff to *Ldr., Tech. Staff* (S. L. Simon, Computer & Control Products, Burlington)

**F. J. Kennedy:** from Senior Project Member, Tech. Staff to *Ldr., Tech. Staff* (S. L. Simon, Computer & Control Products, Burlington)

**W. A. Delaney:** from Senior Project Member, Tech. Staff to *Ldr., Tech. Staff* (S. L. Simon, Computer & Control Products, Burlington)

**N. Meliones:** from Senior Project Member, Tech. Staff to *Ldr., Tech. Staff* (S. L. Simon, Computer & Control Products, Burlington)

**J. G. Sambalino:** to *Ldr., Engineering Systems Projects* (A. A. Paris, Mgr., Airborne Communications, Camden)

**R. N. Knox:** to *Ldr., Tech. Staff* (J. P. Eugley, Mgr., Sub-System Development, Burlington)

**Semiconductor & Materials Division**

**P. E. Kolk:** from Engr., Product Development to *Engineering Ldr., Product Department* (R. Painter, Somerville)

**E. Van Wagner:** from Engr., Manufacturing to *Engineering Ldr., Manufacturing* (R. O'Brien, Somerville)

**R. A. Donnelly:** from Engr., Manufacturing to *Engineering Ldr., Manufacturing* (F. L. Wildes, Type Engineering, Findlay, Ohio)

**D. H. Wells:** from Engr., Manufacturing to *Engineering Ldr., Manufacturing* (F. L. Wildes, Type Engineering, Findlay, Ohio)

**H. Goshgarian:** from Engineering Ldr., to *Mgr., High Speed Products* (J. P. McCarthy, Somerville)

**R. Fournier:** from Senior Engr., Product Development to *Engineering Ldr., Product Development* (J. W. Englund, Somerville)

**Defense Engineering, DEP**

**E. A. Szukalski:** to *Ldr., Design and Development Engrs.* (G. H. Lines, Mgr., Design Standards)

**Major Systems Division, DEP**

**N. Alperin:** from Mgr., Info. Processing Applications to *Mgr., Info. Processing Systems* (H. F. Baker, Moorestown)

**A. Zeichner:** from Ldr., Sys. Engineering to *Mgr., Evaluation & Analysis* (H. F. Baker, Moorestown)

**R. Renfrow:** from Ldr., Sys. Engineering to *Mgr., Sys. Integration & Growth* (H. F. Baker, Moorestown)

**J. Sarafian:** from Admin. Tech. Coord. to *Mgr., Project Engineering* (D. Cottler, Moorestown)

**J. Harvill:** from Ldr., Engineering Sys. to *Mgr., Engineering Specs.* (J. Herbert, Moorestown)

**L. Peterson:** from Ldr., D.&D. Engineering to *Mgr., Engineering Manuals* (J. Herbert, Moorestown)

**H. Baker:** from Mgr., Sys. Integration to *Mgr., BMEWS Sys. Engineering* (D. Cottler, Moorestown)

**R. Mitchell:** from Engr. to *Ldr., Engineering Sys. Projects* (J. Seligman, Moorestown)

**R. Simendinger:** from Engr. to *Ldr., Engineering Sys. Projects* (J. Harvill, Moorestown)

**J. Amatrudi:** from Engr. to *Ldr., D.&D. Engineering* (L. Peterson, Moorestown)

**R. Wimberger:** from Engr. to *Ldr., Engineering Sys. Projects* (L. Hodson, Moorestown)

**J. LoPresto:** from Engr. to *Ldr., Sys. Engineering* (N. Alperin, Moorestown)

**F. Beck:** from Ldr., Engineering Sys. Projects to *Mgr., Engineering Sys. Projects* (H. Eigner, Moorestown)

**R. D. Kemp:** from Engr. to *Ldr., D.&D. Engineering* (L. G. Peterson, Engineering Control, Moorestown)

**O. E. Fayard:** from Engr. to *Ldr., Sys. Engineering* (S. G. Miller, Space Operation, Moorestown)

**D. M. Cottler:** from Mgr., Advanced Projects to *Mgr., BMEWS Engineering* (J. J. Guidi, BMEWS Engineering, Moorestown)

**Missile and Surface Radar Division, DEP**

**R. Capron:** from Ldr., D.&D. Engineering to *Admin., Field Engineering Product Assurance* (M. Rogers, Moorestown)

**J. J. Bisaga:** from Engr. to *Ldr., D.&D. Engineering* (E. S. Lewis, Antenna II Unit, Moorestown)

**Astro-Electronics Division**

**W. J. Haneman:** from Engr. to *Ldr., Engrs.* (M. V. Sullivan, Mgr., Video Systems)

**R. Herman:** from Engr. to *Ldr., Engrs.* (R. B. Marsten, Mgr., Space Communication Systems)

**F. J. Bingley:** to *Ldr., Engrs.* (J. Lehmann, Mgr., Space Observation Systems)

**Home Instruments Division**

**W. F. Groene, Jr.:** from Engr. to *Ldr., Liaison Engrs.* (J. M. Wright, Mgr., Plant Resident Engineering, Bloomington, Ind.)

**E. J. Evans:** from Ldr., Liaison Engrs. to *Mgr., Resident Engineering* (L. M. Krugman, RV Product Engineer, Bloomington, Ind.)

**Data Systems Division**

**S. Nozick:** from Prin. Member, Systems Engr. Staff to *Ldr., Sys. Engr.*, (Dr. Nolde, Van Nuys)

**H. Grossobohlin:** to *Ldr., Project Engr. Staff* (B. G. Lewis, Van Nuys)

**A. M. Berg:** from Prin. Member, Project Engr. Staff to *Ldr., Project Engr. Staff* (S. Gewant, Van Nuys)

**G. L. Cohill:** from Sr. Member, Systems, Engr. Staff to *Ldr., Systems Engr. Staff* (Dr. Nolde, Van Nuys)

**E. Byrne:** from Ldr., Dev. & Des. Engr. Staff to *Mgr., Electronic Dev. & Des.* (J. Cornell, Van Nuys)

**W. Swarthout:** from Ldr., D.&D. Engr. Staff to *Mgr., Reliability Assurance* (L. Jacobs, Van Nuys)

**RCA Service Company**

**H. D. MacGregor:** from Ldr., Engrs. BMEWS to *Ldr., Senior Engrs. BMEWS* (R. G. Tracy, Fylingdale, England)

**H. W. Trigg:** from Advanced Systems Coordinator to *Staff Engr.* (E. Coan, Autec, Missile Test Project, Fla.)

**H. W. Steward:** from Adm., Performance Analysis to *Ldr., Senior Engrs.* (W. M. Leonard, ZI Site, Colorado Springs)

**R. E. Carter:** from Engr. to *Ldr., Engrs.* (E. L. Waltz, Engineering & Technical Services, Cherry Hill)

**Electron Tube Division**

**D. H. Gish:** from Engr., Product Development to *Mgr., Standardizing* (Mgr., Operations Services, Lancaster)

**J. K. Glover:** from Mgr., Standardizing to *Mgr., Life Test and Data* (Mgr., Operations Services, Lancaster)

**J. L. Straub, II:** from Engr. Manufacturing to *Mgr., Specifications and Project Engineering* (Mgr., Operations Planning and Control-Power Tube, Lancaster)

**L. J. Caprarola:** from Mgr., Methods & Process Laboratory to *Mgr., Thermoelectric Device Development* (R. L. Klem, New Products Engineering, Harrison)

**R. C. Fortin:** from Admin., Project Coordination to *Mgr., Methods & Fabrication Laboratory* (L. J. Caprarola, Thermoelectric Device Development, Harrison)

**R. F. Dunn:** from Mgr., Receiving Tube Development to *Mgr., Field Engineering* (L. D. Kimmel, Entertainment Sales, Harrison)

**W. O. Watts:** from Mgr., Manufacturing Standards to *Mgr., Engineering Standards* (G. Wolfe, Engineering Methods & Standards, Harrison)

**M. DeArmas:** from Manufacturing Engr. to *Mgr., Process Quality Control* (R. A. Jacobus, Plant Quality Control, Harrison)

## DEGREES GRANTED

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|---|---|
| **G. Weinstock,** DEP | MS, Columbia Univ. |
| **H. Halpern,** ACC | MSEE, University of Pennsylvania |
| **R. A. Baugh,** ACC | MSEE, Drexel Institute of Technology |
| **E. D. Grzegorzewski,** DEP-AED | BS, LaSalle University |
| **S. Fiarman** | MS, Rutgers University |
| **R. A. Hammell,** DEP | MSEE, University of Pennsylvania |
| **J. E. Saultz,** DEP | MSEE, University of Pennsylvania |
| **W. Blydenburgh,** ETD | BSME, Fairleigh Dickinson |
| **N. Cutillo,** ETD | BSEE, Fairleigh Dickinson |
| **J. S. Posner,** ETD | LLB, Fordham University |
| **G. Metalitis,** ETD | BSIE, Fairleigh Dickinson |
| **R. E. Brown,** ETD | MSEE, Stevens Institute of Technology |
| **M. DeArmas,** ETD | MSIE, Stevens Institute of Technology |
| **P. J. Harff,** ETD | MSIE, Stevens Institute of Technology |
| **J. P. McDonald,** ETD | MSEE, Newark College of Engineering |
| **H. Anderson,** ETD | MBA, Harvard University |

## STAFF ANNOUNCEMENTS

*DEP Aerospace Communications and Controls Div.:* **S. L. Simon,** Chief Engr., Engineering Dept., Burlington, announces his staff as follows: **I. C. Akerblom,** Mgr., Engineering Services; **A. H. Benner,** Mgr., Advanced Systems and Techniques; **C. W. Brigham,** Mgr., Design Operations and Controls; **E. B. Galton,** Mgr., Reconnaissance and Surveillance Products; **E. C. Kalkman,** Mgr., Systems Support Products; **G. M. Nonnemaker,** Mgr., POSS Project; **S. L. Simon,** Acting Mgr., Computer and Control Products; and **C. W. Steeg,** Mgr., OFC Saturn Project.

Also in DEP-ACCD, **C. K. Law,** Mgr., Programs Management, announces his organization as follows: **F. L. Bernstein,** Mgr., Marine Warfare Programs; **J. A. Doughty,** Mgr., Plans and Liaison; **H. C. Huber,** Mgr., Sideband Programs; **W. Keiser,** Mgr., ECM Programs; and **H. C. Lawrence,** Mgr., DATS Programs.

*Electronic Data Processing:* **A. D. Beard,** Chief Engr., Engineering, announces his staff as follows: Mr. Beard is serving as Acting Mgr., Data Processing Device Engineering; and as Acting Mgr., Design Support; **C. M. Breder,** Mgr., Admin. and Control; **L. Iby,** Mgr., Mechanical Coordination; **R. E. Montijo,** Mgr., Systems Engineering; **A. J. Torre,** Mgr., Peripheral Product Engineering; and **J. J. Worthington,** Mgr., 601 Project. Reporting to Mr. Breder are: **E. R. Chierici,** Mgr., Budgets and Expense Control; **T. T. Patterson,** Mgr., Technical Publications; **K. H. Spruth,** Mgr., Schedule Control and Engineering Releases; **K. E. Thomas,** Mgr., Admin. Services; **T. R. Thorpe,** Mgr., Drafting: Reporting to Mr. Torre are: **R. D. Grapes,** Mgr., Tape Station Design; (Mr. Torre is acting Mgr., Alpha-Numeric Readers). Reporting to Mr. Worthington are: **A. T. Ling,** Mgr., Machine Logic Engineering; **J. J. O'Donnell,** Mgr., Circuit Standards and Packaging Engineering; and **G. J. Waas,** Mgr., Circuit and Memory Engineering.

*Corporate Planning:* **T. A. Smith,** Executive Vice President, Corporate Planning, has named **J. M. McKnight** as Admin., Corporate Planning Data Analysis.

*RCA Service Co., MTP., Florida:* **Dr. Lawrence E. Mertens** has been named Staff Scientist at MTP., as announced by **G. Denton Clark,** Mgr., Missile Test Project. Dr. Mertens transferred to MTP. from DEP-Surf Com, Camden, where he was Mgr., Digital Communications Equipment Engineering. At MTP., he will be responsible for providing advice and direction relative to instrumentation on the Atlantic Missile Range.

*Product Engineering, corporate staff:* **D. F. Schmit,** Staff Vice President, Product Engineering, announces that **J. P. Veatch** has been appointed Director, RCA Frequency Bureau. Mr. Veatch's staff includes: **J. F. Eagan,** Mgr., Camden Office and **W. Mason,** Mgr., New York Office.

*DEP Surface Communications Division,* Programs Management: **J. C. Donofrio,** Mgr., Micro-Module Programs, has named **C. A. Rammer** as Mgr., Micro-Module Engineering. Reporting to Mr. Rammer are: **D. Mackey,** Mgr., Engineering (Adv. Micro-Module Cir. and Systems); **J. D. Gell,** Mgr., Engineering (Industry Support and Assem. Techniques); Mr. Rammer is acting Mgr., Engineering (Module Systems and circuit Engineering).

Also in Surf Com, **O. B. Cunningham,** Chief Engineer, Engineering Department, has announced the following appointments on his staff: **J. L. Grever,** Mgr., Magnetic Recording Equipment, Engineering; **A. H. Kettler,** Staff Engineer; and **R. L. Rocamora,** Mgr., Digital Communications Equipment Engineering.

*RCA International Division, Clark, N. J.:* **E. J. Dailey** has been named Division Vice President, Associated Companies Operations, RCA International Division, by **D. C. Lynch,** Vice President and Managing Director of the Division. Mr. Dailey will, under the direction of Mr. Lynch, be responsible for the policies of the RCA affiliated companies overseas and the world-wide coordination of these policies with the manufacturing, engineering, marketing, and administrative functions of these companies.

*Industrial Tube Products Department:* **E. E. Spitzer,** Mgr., Power Tube Operations, names his staff as: **W. P. Bennett,** Mgr., Regular Power Tube Engineering; **J. J. Fencel,** Mgr., Regular Power Tube Manufacturing; **C. Hanlon,** Mgr., Super Power Tube Manufacturing; **J. W. Hollingsworth,** Mgr., Quality Control-Power Tube Operations; **R. T. Rihn,** Mgr., Operations Planning and Controls-Power Tube; **M. B. Shrader,** Mgr., Super Power Tube and Space Components Engineering; and **P. T. Smith,** Mgr., Power Tube Applied Research Laboratory, Princeton.

*DEP Data Systems Division, Van Nuys, Calif:* **Dr. Henry M. Watts** has been appointed Manager of Systems Engineering, DSD.

*DEP Surface Communications Division, Cambridge, Ohio:* **R. V. Miraldi** formerly Plant Mgr., Cambridge, Ohio plant of the DEP Surface Communications Division has been named to the staff of **F. Sleeter,** Vice President, Manufacturing Services, RCA Corporate Staff. Mr. Miraldi in his new assignment will be responsible for analyzing RCA plant operations both domestic and foreign and in developing plans designed to make these plants more competitive. In recent months he has traveled to England and Italy on such assignments. **C. A. Steuernagel** has been appointed Plant Mgr., of the DEP Surface Communications Division, Cambridge, Ohio plant, reporting to **S. W. Cochran,** Division Vice President and General Mgr. Mr. Steuernagel was formerly Mgr., Manufacturing Engineering at Cambridge.

### NEW WING ADDED TO RCA LABORATORIES

Completion of a new three-floor, 33,000-square-foot wing at RCA Laboratories in Princeton, N. J., has provided RCA scientists with 40 new research laboratories plus expanded office, shop and conference areas. Significantly, 25 of these laboratories, housed on the upper two floors of the new facility, are designed exclusively for *materials research.* For this reason, each features "walk-in" chemical hoods and electrostatically cleansed air supplies whose temperature and humidity can be controlled independently from laboratory to laboratory.

Reinforcing a growing trend which, in recent years, has seen the Laboratories move away from work on specific electronic equipment and systems towards more fundamental investigations, these 25 research units will concentrate, initially, on studies of semiconductor, superconductor and thermoelectric phenomena. Such work is expected to contribute importantly to new business opportunities for RCA, especially in the areas of thin-film transistor circuitry, ultra-high-field magnets and direct energy conversion.—*C. W. Sall.*

## PROFESSIONAL ACTIVITIES

*DEP-MSD, Moorestown:* **Walt Dennen** has been named an Associate Editor of the *Review* of the Society of Technical Writers and Publishers. He is also serving as an Associate Editor of the *Transactions* of the IRE-Professional Group on Engineering Writing and Speech.—*E. Lacy*

**Irmel Brown,** was one of three industry representatives appearing on the "Panel on Technical and Scientific Fields" as a part of the Employment Opportunities Workshop for College Students held last June at Temple University.

**Kenneth Hicks** completed the UCLA June 18-29 short course on *Space Optics, Theory and Applications.—R. R. Welsh*

**Henry Phillips** is First Vice President of the Engineering Society of Southern New Jersey, for 1962-63, a branch of the National Society of Professional Engineers.

*RCA Victor Record Division, Indianapolis:* Eleven engineers participated in the First Annual Career Guidance Day for high-school students sponsored by the Indianapolis Engineering Societies Committee earlier this year. Exhibits were prepared and manned by twenty-two local industries and universities demonstrating the various engineering specialties. Those RCA men who served on the committee were **Don Hoffman, Larry Jones, A. M. Max, Frank McCann, E. D. Mahoney,** and **Arnold Viere.** Exhibits were prepared and shown by **Dallas Andrews, Wes Hall, Don Hoffman, Clyde Hoyt, Harold Jense, A. M. Max, Charles Rifle** and **Arnold Viere.**—*M. L. Whitehurst*

*DEP-DSD, Bethesda, Md.:* **Sid Kaplan** has been appointed Chairman of the Nominating Committee for the New Jersey Section of the Methematical Association of America.

**H. J. Carter** was Chairman of the Publications Committee for the IRE-PGEWS National Symposium, held in Washington, D.C., Sept. 13-14, 1962.—*Jim Carter*

*DEP Central Engineering, Camden:* **D. I. Troxel** has been elected Vice-Chairman of the Philadelphia Chapter of the IRE Professional Group on Reliability and Quality Control for 1962-1963. **S. K. Magee** has been elected to serve as Vice Chairman of the EESC (Electronic Equipment Specifications Committee) of the AIA for the year 1962. **A. H. Rudrauff** was awarded a 25 Year Certificate by the American Society for Metals at the Honors Night, held April 27, 1962 at the Germantown Cricket Club. —*P. F. Kennedy*

*DEP SurfCom, Cambridge:* In May of this year, a Business-Management seminar was held for Cambridge Leaders and Managers. Also, Cambridge subsection of the IRE was recently formed, with **P. J. Riley** as Chairman.—*P. J. Riley*

*DEP Applied Research, Camden:* **E. E. Moore** has been named Vice Chairman of the IRE Professional Group on Electron Devices for 1962-63. **W. Hannon** was named Vice Chairman of the IRE Professional Group of Circuit Theory for 1962-63. —*M. G. Pietz*

## IRE-PGEWS LISTS BROAD OBJECTIVES OF SIGNIFICANCE TO ALL ENGINEERS; RCA WELL REPRESENTED ON NATIONAL COMMITTEE

Today, all engineers and scientists are involved with creating and using a vast amount of technical information—reports, papers, presentations, etc. The usefulness of this wealth of documentation is largely determined by the intellectual effort and writing quality applied by its authors, and by the efficiency with which such information is published, disseminated, and stored—so that it can be readily searched, retrieved, and *used* when it is needed.

Better methods for implementing this technical-communications continuum are constantly being sought. Within the Institute of Radio Engineers, the Professional Group on Engineering Writing and Speech (PGEWS) is dedicated to the objective. PGEWS future plans are broad in scope, and through local meetings, national symposia, and publications, will deal with topics ranging from writing and presenting technical material to the application of modern methods for dissemination, storage, and retrieval of technical information. PGEWS can serve both as a valuable source of "how-to" information, as well as a focal point for feedback of problems in technical communication.

RCA is well represented on the PGEWS national-committee organization: **Chet Sall,** RCA Laboratories, is the National Chairman of the Professional Group for 1962-63, and **Eleanor McElwee,** ETD, is continuing as Secretary-Treasurer. Excutive Committee members for coming terms include **Charley Meyer** (also Co-Chairman, Ways and Means), ETD; **Ed Byrum,** ETD; and **Tom Patterson,** EDP (also Editor, PGEWS *Newsletter*); **Ed Jennings** RCA ENGINEER, is serving as Editor of the PGEWS *Transactions,* with **Walt Dennen,** DEP-MSD, as Associate Editor.

## GEORGE KUMPF RETIRES

**George Kumpf** was honored by ninety of his many RCA friends and associates at a farewell dinner recently, on the occasion of his retirement. George started with RCA in 1930, and worked on the first production TV receivers and on lightweight radar. Then, in 1945, he was one of the original group of 15 engineers that designed TV Transmitters and antennas after WW II. Since 1945, he has been with the Broadcast Division Antenna Engineering group in Camden, where his work on many antenna mechanical designs (e.g., superturnstile, Empire State TV, supergain, traveling wave) made him an expert in his field.

—*H. E. Gihring*

## FUTURE ENGINEERS OF AMERICA

A group of high-school physics students that recently visited the Data Systems Division, Van Nuys, were representatives of an especially interesting new national organization, the *Future Engineers of America.* Organized only three years ago, FEA now has seventy-five chapters throughout the United States. One of its most active units is California's San Fernando Valley Council with more than 400 members. The Council has an 18-room science center (provided by the Los Angeles City Board of Education). Guidance and materials are provided by local industries and individual engineers.

—*D. J. Oda*

### CORRECTIONS TO THE AUG.-SEPT. 1962 ISSUE

In "Resolution of Electrostatic Patterns" by I. M. Krittman, (*Engineering and Research Notes,* p. 56), two typographical omissions obscured the meaning of the text. Correct as follows (italicized words to be added):

Third para., first line:

If one used standard *guns,* estimates of . . .

Sixth para., fifth line:

Multiple-field camera response *was* definitely improved . . .

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In "Spark Source Mass Spectrometry for the Trace Impurity Analysis of Solids," by Dr. J. Kurshan, the captions for Figs. 4 and 5 were transposed, and should have read:

Fig. 4—Schematic diagram of spark-source, double focussing mass spectrograph.

Fig. 5—180° direction focussing analyzer.

Also, on p. 35, first column, 7th line from bottom, text should read: *in Fig. 4* . . .

° ° ° °

In "The Signal Corps DEE," by D. B. Dobson and L. L. Wolff, in the *Prologue,* p. 16, second column, line 18, should read:

Programs launched in *1955.* That . . .

Also, in the *Selected Bibliography,* item 2 should read:

2. Lecture Notes for the Design *Course* . . . etc.

## BEHIND EACH ISSUE—THE EDITORIAL REPRESENTATIVES

Behind every issue of the RCA ENGINEER is the indispensable planning and coordinating of papers carried out by Editorial Representatives. Shown here are (left to right): Bob Hurst, Ed Rep from the Broadcast Division; RCA ENGINEER Staff members Judith Sarich, Mrs. Carmella Marchionni, and Ed Jennings, Assistant Editor; Tom Greene, DEP-MM&SR Ed Rep; and Dave Dobson, Ed Rep from DEP-ACCD (Burlington). Bob is regularly engaged in planning important papers from his Division. Tom and Jess Epstein, Administrator, Antenna Systems, DEP-MM & SR, were responsible for much of the content of this issue, and deserve credit for suggesting and obtaining the color cover photo. Their work on this issue began several months ago when they developed and proposed over 30 abstracts of microwave papers, from which the MM & SR papers in this issue were gleaned. Dave did a similar job on the previous (August-September) issue on automatic checkout both on the papers and in suggesting the cover. These men also deserve much credit for the way they have encouraged and coordinated the writing of papers in their respective activities for publication in outside journals. Miss Sarich recently joined the RCA ENGINEER staff and is now handling the mailing list records and RCA papers approval records. Mrs. Marchionni (until recently Miss Serafino) is the RCA ENGINEER Editorial Secretary.

## W. M. MORSELL, NEW ACCD AD REP

**W. M. Morsell** is now serving as RCA ENGINEER Editorial Representative for Design and Development Engineering, DEP Aerospace Communications and Controls Division, Camden. He received the BME from Pratt Institute in 1940 and worked as an electronic engineer in industry for several years. In 1948, he became Chief, Engineering Physics Section at the Franklin Institute. Upon joining RCA in 1958, he was responsible for the financial control and coordination of schedules for the Pre-production Program for ASTRA, and for Air Force Time Division Data Link Value Improvement Program. He was made Project Leader in 1960. He has performed studies on management methods such as PERT, Line-of-Balance, and graphical presentation of cost data, and is presently working on setting up a PERT/COST activity for ACCD Engineering. Mr. Morsell is a member of the American Ordnance Association, Soc. of American Military Engineers, Assoc. of the U.S. Army, Air Force Assoc., and American Management Association.

## DIGITAL COURSE AT DSD

One of the most popular courses in Data Systems Division's after-hours program is a graduate level course entitled *Special Topics in Digital Techniques.* Some 190 engineers initially applied for admission to the course, which had to be divided into two sessions, with instructors drawn from DSD Engineering. Topics covered include fundamentals, circuits, memories, and logics, each with practical material pertinent to DSD activities.—*D. J. Oda*

## MSD SPACE TECHNOLOGY COURSE

A series of lectures on *Space Technology* given by recognized specialists from several Universities and Laboratories was recently completed by approximately sixty engineers, leaders and managers of the DEP Major Systems Division at Moorestown.

The material offered was of advanced graduate level and was sponsored by the Systems Engineering Section of MSD, **H. W. Collar,** Manager, and was directed by a committee consisting of **I. N. Brown,** Chairman; **J. M. Gwinn, G. Luchak, A. Korbin** and **M. M. Mandelkehr.**

## TWT DESIGN COURSE AT ETD

The following series of discussions constitutes a special Traveling-Wave Tube Design Course that has been offered this year to all engineers of ETD Microwave Operations in Harrison. The discussions are being presented by **Ed Bliss,** Senior Engineer on the staff of the Traveling Wave Tube Design and Applications Group.—*H. Wolkstein*

I. *Elementary TWT Design*

II. *Intermediate TWT Design:* Determination of helix loading and effect on impedance; Frequency centering, bandwidth and efficiency; Calculation of gain vs. frequency; Design of tube to meet specific requirements.

III. *Advanced TWT Design:* Calculation of gain vs. frequency for fixed and varying helix voltage.

IV. *Associated Components and Effects:* Electron guns; Focusing; Magnetic Fields; Oscillations, forward wave, backward wave, gun and ion; Other slow-wave structures.

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A TECHNICAL JOURNAL PUBLISHED
BY PRODUCT ENGINEERING.
"BY AND FOR THE RCA ENGINEER"

RADIO CORPORATION OF AMERICA

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