OBJECTIVES

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 engineering 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.

OUR COVER

. . . the RCA Television Tape Recorder is the subject of discussion by A. H. Lind, Manager, Electronic Recording Engineering (left), and N. L. Hobson, Manager, Quadruplex Recorder Design (right), both of whom played prominent roles in the design and development of the recording system. Today, this system is an important part of RCA's product line and has enhanced RCA's continuing stature in the television broadcasting industry. See "Magnetic Heads for TV Tape Recording," by J. D. Bick and F. M. Johnson, on P. 14 of this issue.

BROADCAST ENGINEERING

Historically, RCA has always been in the broadcast business. Consistently, RCA engineers pioneered many of the important advancements that have been made, from the early days of radio to the present state of television.

RCA has not only pioneered in the most miraculous of modern media for mass communication — more importantly, we have retained this leadership. Because of superior product, our engineers have garnered an enviable reputation. Inevitably, the techniques developed in our engineering laboratories have found their way to acceptance by the industry.

It almost goes without saying that broadcasting is father to the electronics industry as we know it today. Application of vacuum-tube circuitry was at one time restricted mainly to radio communication and broadcasting. From this, there were developed electronic control circuits and military applications of electronic technology. Thus, the plant became a tree — with its many branches of electronic applications.

In the broadcast industry, a major portion of studio and transmitter equipment is manufactured by RCA. There is always a certain prestige attached to the owner of the Cadillac, and in the broadcast business, this standard of excellence *is* RCA. A station considers it a mark of distinction to have this equipment on its premises.

Educators are looking with favor upon televised instruction, as the performance of quality equipment and the possibilities of integrated television systems reveal the massive stature of the medium. Again, RCA engineered systems are being selected by large multi-school counties, state-wide systems and universities.

Here at RCA, many of the most promising developments in the field of electronics have been spurred by broadcast engineering creations. They have provided the kind of profits that make it possible to go forward in many other avenues of electronics — developing new processes and products.

It is a realistic challenge for creative genius to apply advanced electronic developments to the problems of the broadcast industry. It represents an opportunity for the ambitious engineer to go far into high places in this affluent and powerful industry, as well as in his own corporation.

V. E. Trouant

V. E. Trouant
Chief Engineer
Broadcast and Television Equipment Division
Industrial Electronic Products
Radio Corporation of America

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The Engineer
and the
Corporation

PROJECT ADMINISTRATION
. . . Its Role in Engineering

by **K. B. BROWNING and L. H. DORFMAN**
Surface Communications Division
DEP, Camden, N. J.

How does the concept of project administration affect engineers and their work? Can it relieve the engineer, leader, and manager from time-consuming administrative detail? Does it provide better over-all program management? These are vital questions frequently asked by many engineers, both in and out of management. The answers are important to the engineer and RCA.

GROWING NONTECHNICAL NEEDS

As a result of enlarged customer requirements, today's engineers and scientists are often beset with many nontechnical demands. In addition to being strong technically, an engineer is often confronted with administrative demands requiring many of the management disciplines. Further emphasis on economic and business aspects is reflected by the various governmental agencies in their stringent requirements for sound industrial business practices. Cold War, inflation, and rising taxes demand that such agencies obtain top technical results with a relatively small amount of well-spent dollars. This philosophy has been passed on to the engineering management of the electronics industry.

In large companies, such business and administrative functions in the past were of only remote concern to an engineer in his daily work. But today, the greater complexity of products and the involvement of many engineers, or groups of engineers, in producing a given product makes these business and administrative problems of direct concern to engineers.

Yet, the engineer knows he must devote virtually all his time just keeping abreast of new scientific developments in his technical field. How then can he, at the same time, do justice to the proper administration of both the business and engineering aspects of his program in every respect? The details of project planning, progress, and results; the schedules to be established and met; cost control and other financial matters; the manning, procurement requirements, and production coordination; and the many detailed requirements of the customer all need attention. Thus the engineer is faced with conflicting interests and responsibility.

ENTER THE PROJECT ADMINISTRATOR

If the nontechnical requirements of a program consume increasing amounts of an engineer's time, the engineer's technical value can reach a point of diminishing returns. It becomes impractical and costly to continue to use specialized engineering talent to perform functions which could be done more economically and equally as well by nontechnical personnel. To alleviate this situation, a *project administrator* can assume the responsibility for nontechnical requirements of the program.

At the time the project administrator is assigned to the program, his basic objective is to relieve the engineer of nontechnical requirements of the program by monitoring, coordinating, and directing the business functions. Of course, engineering management retains over-all responsibility for total job performance. Similarly, the project administrator, in his capacity, does not supplant other business functions of the organization, such as contract administration and programming—rather, the administrator is responsible for helping them do their job as it affects *his* program. In accomplishing this, the project administrator is responsible for monitoring and coordinating the business aspects, and for reporting program status so that engineering management can anticipate problem areas and act quickly. The project administrator is also valuable in assisting those company functions that are affected by, but are not closely enough involved with, engineering activities on a day-to-day basis. (See table of *Project Administrator Responsibilities.*)

The amount of time and effort that the administrator contributes to these facets of the program is dependent, to a large extent, upon the type of contract and the nature of the program. For example, when he is assigned to a study contract, his concern with production will be nil; his primary interests will be with manning, cost control, and engineering performance in conjunction with established schedules.

THE TYPICAL PROGRAM

The concept of project engineering is basically a delegation of responsibility for a program to one individual—the engineering project manager. He is assigned the over-all responsibility for all functions contributing to the successful completion of the job. Typically, he has a small staff of technical personnel to coordinate the contributions of other engineering functions. Such engineering functions—for example, systems, development, design, models, and installation—are performed by engineering groups or outside suppliers over whom the project manager has no direct authority. Therefore, any necessary authority must flow through the chief engineer in situations which cannot be resolved directly or by middle management. The project administrator's dealings with the business functions *are almost directly analogous*, in that he has no direct authority over them—he utilizes the authority of the project manager and higher management if the situation warrants it.

FUNCTIONS OF PROJECT ADMINISTRATION

In order to demonstrate the functions of a project administrator, they will be discussed in terms of a typical research-and-development program. When a request to bid on such a program comes in, the project administrator is assigned to participate in the preparation and submittal of both the technical and cost proposals.

Cost Proposals and Schedules

The preparation of the cost proposal entails close liaison with the appropriate engineering group. Once the elements affecting costs have been reviewed and defined by engineering, the project administrator can relieve the engineers of the detail of refining the bulk of information into an acceptable, management-approved cost estimate.

With the award of a contract, the project administrator's responsibilities broaden. He helps establish a shop order system (for accumulation of costs) most suitable for the requirements of the contract. He will also establish schedules for the program on a task-by-task, or work-area basis. These schedules will be in accord with the statement of work and the negotiated contract, and will embody such particulars as manning requirements, expenditures and milestones of progress.

Control and Liaison

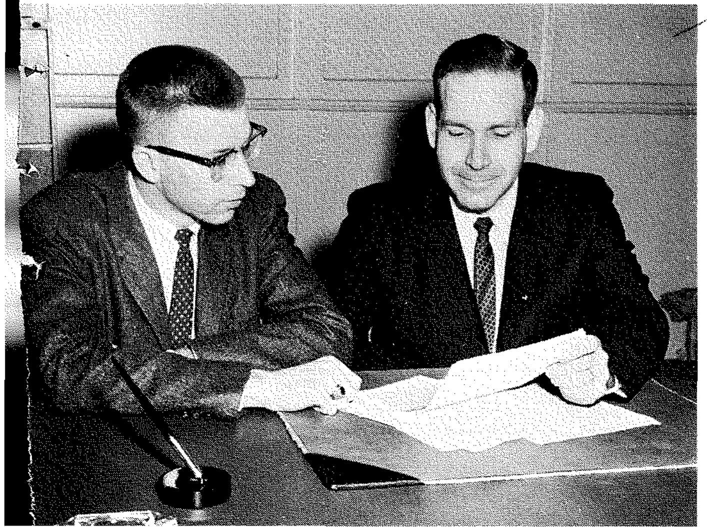
As the program progresses, the project administrator monitors and controls progress by 1) issuing requisitions for purchased materials or services, 2) monitoring time records to ensure on-schedule performance, 3) monitoring accounting records to ensure performance in accordance with cost schedules, 4) coordinating deliveries of contract items to the customer, 5) monitoring security requirements, 6) maintaining complete and current files for easy engineering reference, and 7) handling any miscellaneous nontechnical items which would otherwise consume valuable engineering time.

The project administrator maintains regular liaison between the engineering and business project functions. Daily activities bring the administrator into contact with accounting, contract administration, operations control, purchasing, receiving, and shipping. Additionally, he may make contact with subcontractors and outside vendors where coordination of nontechnical matters is required.

KEMPTON B. BROWNING received a B.A. Degree in English from Colgate University in 1956. Following graduation, Mr. Browning joined KSM Products, Inc. in Delaware Township, N. J. where he served as executive secretary to the president of that firm. He joined RCA in April of 1957 as an Engineering Commitment Coordinator in Surface Communications Engineering, where he was engaged in general engineering administration activities. In September, 1959 he then advanced to the position of Administrator, Project Coordination, for the Camden portion of the Air Force 480L Global Communications Program, handling all administrative, nontechnical functions. He now has similar responsibilities on the ComLogNet Circuit Switching Unit Program. He is a member of Phi Kappa Tau.

L. H. DORFMAN received a BS in Electrical Engineering from the University of Texas in 1954. After graduation, he served for two years as Naval Electronics Materiel Officer aboard a destroyer. When he was released from active duty, he attended the University of Pennsylvania, where he received an MBA in Industrial Management in 1959. Upon graduation, he joined RCA Surface Communications' Management Training Program and since has become an Administrator, Projects Coordination.

The authors, K. B. Browning (left) and L. H. Dorfmann.



PROJECT ADMINISTRATION RESPONSIBILITIES

1. Coordination, allocation, and scheduling of engineering and production of both RCA and subcontractors; review of progress and issuance of all necessary technical and business reports.
2. Coordination of contract-schedule releases from engineering to production.
3. Coordination of the purchase of supplies, equipment and facilities to assure fulfillment of contract on schedule.
4. Liaison with product, subcontractor representatives on nontechnical matters.
5. Maintenance of vendor, subcontractor, and production follow-up according to established schedules.
6. Collaboration with Quality Control to assure performance to quality standards established by the customer and the company.
7. Monitoring of operating expenditures to balance performance against established cost estimates; real or anticipated variances are brought to the attention of supervision.
8. Maintenance of production records.
9. Collaboration with Contract Administrator.
10. Reporting of performance and problem areas to supervisory and management personnel concerned with the program.

Shop Order System

Interdependency between the project engineering and the accounting functions may best be illustrated by the engineering shop order system.

The administrator assigns a number of shop orders, budgets the contract funds between shop orders, and then calls upon accounting to actually issue them. During the course of the contract, new shop orders are opened and current ones modified; as portions of the contract are completed, shop orders are closed. The administrator, while monitoring all charges to the shop orders, calls upon accounting to review questionable charges. The administrator is expected to plan and predict future costs for his program and provide the financial reporting activity with estimated expenditure rates for each shop order and for the project as a whole. Such information, along with actual costs to date is translated into a contract cost summary; it is one of several reports presented to the project manager to keep him abreast of the status of his program.

Liaison with Contract Administration

A second area requiring close liaison is in the field of contract administration. The project administrator keeps the contract administrator advised of the engineering status of the contract. Where an increase in scope or an over-run is evident, the project administrator notifies marketing well in advance, so that they can: 1) request an engineering cost estimate, 2) notify the contracting officer of the impending situation, and 3) request the additional funds and provide back-up material to support the reported increase in scope or over-run. He then reviews the engineering cost estimate for errors or omissions and follows it through the engineering approval cycle to assure that the due date is met, coordinating any necessary revisions.

Progress Reports

When periodic progress reports are required by the customer, the administrator does the detail work. Information is collected, organized, and edited by the administrator, particularly where no technical depth in discussion is required. Other detail work in reporting the use and amount of overtime, and in monitoring trip-report submission is done by the administrator.

Purchasing

Whenever the project calls for the purchasing of hardware or services, the project administrator proves quite useful as liaison between engineering and the purchasing function. Depending on the complexity of the specification, the engineer or the project administrator may issue the engineering requisition. If the time schedule is critical, the administrator may save several days time by hand-carrying engineering releases through the purchasing cycle. Often when this is done, the purchasing agent will determine a promise date for a high-priority item the same day. As the date of shipment nears, the administrator will double-check with the purchasing agent or his buyer to ascertain if the shipment is on schedule. Wherever the time schedule warrants faster delivery of a critical item, arrangements are made to air-express the item to the factory. Again, the administrator makes arrangements to have the article picked up at the air-express terminal as soon as it arrives. With close coordination, several days may be saved.

In some instances, meetings can be arranged with purchasing and the vendors to discuss a critical delivery of a specialized item. For example, on one high-priority test program, a special magnetic tape was needed quickly. To wait for the manufacturer to schedule the production run would have taken weeks, or even months, for delivery under normal circumstances. After a meeting with the vendor's sales representative on a Friday, arrangements were made to cut into the production run on the following Wednesday. The tape was delivered on the following Monday.

Shipping

Shipping is another area where the administrator coordinates the tasks involved. The engineer should not have to spend his time on a telephone arranging for packing and shipping of a finished product. The administrator should arrange for packing designers to take measurements, prescribe materials to be used in accordance with the contract, and fabricate any special packing items. Once the packing design is completed, the packers, markers, and movers are found and arrangements made for transportation from the plant to the railroad or air terminal. Before any equipment leaves the plant, however, appropriate shipping memos must be issued, with the project administrator providing necessary information. Where the administrator has handled such arrangements, he will be responsible for follow-up, should shipping delays, damage, or other problems produce a customer complaint.

PROJECT ADMINISTRATION BACKGROUND

In order to perform the many associated engineering functions, the project administrator must have a background which encompasses experience and/or higher education. Until recently, an employee could attain enough experience in various parts of the company to warrant his becoming a project administrator solely on this basis. While in some remote cases this still holds true, the requirements for this job have changed with the times. The need for higher education is now a generally recognized prerequisite. Since he deals with people in and out of the company at all levels of management, the project administrator's educational background should enable him to write and speak well, organize and run meetings, meet regularly with customer representatives, and issue various reports.

He must also deal with engineering personnel on a daily basis, so he should have at least a layman's knowledge of engineering and its terms. He is expected to portray himself as a member of engineering management, so he should be familiar with company policies and procedures. And, since he daily coordinates the many group functions, he must have an educational background which encompasses business disciplines.

Conversely, it has been noted that a good educational background is not sufficient in itself to develop a good project administrator. The fact that he deals with administrative functions of the program denotes a need for a comprehensive familiarity with his company and all of its integral parts. This type of "education" is available only through experience.

A LOOK TO THE FUTURE

The future role of project administration in engineering will be characterized by two primary objectives: 1) to improve both the quantity and the quality of the services rendered for the benefit of the engineer, and 2) to provide increased and more effective program control.

As the technical requirements within the "state of the art" increase and the technology of the industry becomes more demanding, the engineer must devote more and more of his time to technical interests. The project administrator will find that requests for his services will grow correspondingly.

Steps are already being taken to utilize various types of mechanization and automation for the issuance of expenditure reports, schedules, and status reports. For example, financial status reports can be issued semimonthly and could be available, through automation, on a weekly basis. Through the use of computers, program evaluation systems, such as PERT (Program Evaluation and Review Techniques) are being utilized as 1) a statistical method for measuring and forecasting R & D progress and 2) as a decision making tool for saving time and in achieving program objectives for which time may be the scarcest item.

The project administrator of tomorrow, with many of today's duties made easier through automation, will be in a position to accept greater responsibilities. He will use every new development in the field of management to provide expedient services; however, the problems in human behavior will undoubtedly be just as complex tomorrow as they are today, thus presenting a continuing challenge.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the advice which was given and the direct contributions which were made in the preparation of this article by R. W. Conner, Mgr., Engineering Projects and F. D. Covely, Mgr., Projects Engineering, Surface Communications Division, DEP.

SEMICONDUCTOR DEVICES . . .
Their Characteristics, Status, and Future

by **E. O. JOHNSON, Chief Engineer**
Semiconductor and Materials Division, Somerville, N.J.

SINCE THEIR BIRTH some ten years ago, semiconductor devices have had an explosive impact on the electronics field. Progress has been made so fast that even specialists have had difficulty keeping abreast of new developments. To some extent the dust has now begun to settle, and some basic trends are emerging.

CONSOLIDATION AND REFINEMENT

The first of these trends is that the semiconductor device field is apparently entering a period of consolidation and refinement. The basic physical tools and concepts are well sharpened. The multitude of fabrication techniques—alloying, diffusion, etching, etc.—are being exploited to the utmost, and refined, optimized, and applied in new combinations.

The most important consequence of this trend is that the user can expect to get increasing device performance per dollar. Performance will improve with respect to frequency, power capability, noise, reliability, ambient temperature, and a general idealization of characteristics. The device cost will eventually be decreased because of technique refinements in mass production. The increased performance per dollar will, itself, have an important consequence. Semiconductor devices will rapidly make inroads into applications hitherto dominated by vacuum devices and, in addition, will open up many new electronic applications previously impractical because of performance, reliability, or cost.

INTEGRATION OF CIRCUIT AND DEVICES

A second trend will be toward an integration of circuit and device. This result follows because the same semiconductor-device fabrication techniques used to make a transistor or diode can be used, more or less simultaneously, to fashion some of the adjoining connections and components. The extent to which this integration can be pushed will depend upon a complicated interdependence between over-all economics, manufacturing process control, the type of application, the performance requirements, and various marketing considerations. At this time, it is not at all clear that integration beyond a relatively few components, or their equivalents, will be practical, or even desirable.

In my opinion, the extreme physical compactness attainable with integration is of secondary importance except in the few special cases where the substantial miniaturization possible with more-conventional techniques is not adequate. Economics, reliability, energy consumption and density, and other performance requirements will usually be of first importance. For example, in many space vehicles, the electronic-system power-consumption problem dominates. System packing densities beyond a few hundred thousand components per cubic foot are physically possible with integration, but these densities lead to severe heat dissipation problems. Some combination of extensive cooling measures, use of micropower devices, and fairly drastic circuit changes will be required to push back this heat barrier.

As we approach the limiting packing density set by heat dissipation, new problems of reliability, component tolerances, and operating speed will arise. The very short signal-propagation times demanded in ultra-high-speed computers require that components be closely spaced. For example, a computer clock rate of 1000 Mc requires that system dimensions be less than one foot.

BETTER APPRECIATION OF DEVICE POTENTIALITIES

The third trend will be a quickening appreciation of device potentialities. Our maturity has grown rapidly during the "electronics revolution" of the last ten years. This growing maturity will do much to improve focus in directing our over-all electronics engineering effort. New semiconductor devices will find their niche much more rapidly than in the past and with less confusion. New devices will not be judged on novelty, but on a critical assessment of their expected relative worth at maturity. A new device will suffer early demise unless its ultimate performance characteristics are sufficiently superior to justify the relatively large investment in research, development, manufacturing, testing, and marketing needed to reach fruition. The increasing demand for proven reliability, and the substantial cost and time that this requirement entails, will tend to increase the necessity for critical evaluations of this nature. A corollary to the increasing demand for reliability will be a trend toward standardization of devices and their specifications.

EDWARD O. JOHNSON received his BS in Electrical Engineering in 1948 from the Pratt Institute. He has pursued graduate studies at Princeton University and at the Swiss Federal Institute of Technology in Zurich. He joined the RCA Labs in 1948, and did research on gaseous conduction and solid-state phenomena. He transferred to the RCA Semiconductor and Materials Division in 1959 as Mgr., High-Temperature Product Development. In July of 1959 he was named Mgr., Advanced Development, and in March of 1960 was named to his present position as Chief Engineer of the Division. Mr. Johnson holds 12 patents and has authored some 20 technical papers. He has been honored for his outstanding work with two *RCA Achievement Awards,* is co-recipient (with Dr. W. T. Webster) of the 1952 *IRE Editor's Award,* and last year was named a *Fellow* of the IRE. He is a member of the Advisory Board of the RCA ENGINEER, and a member of Sigma Xi, Eta Kappa Nu, and the American Physical Society.

No new device capable of challenging the transistor "across the board" has yet appeared. The tunnel and varactor diodes can outperform the transistor only in relatively specialized applications. For computers, my guess is that important discoveries in system organization and the manner of handling digital information will precede the invention of semiconductor devices that could give more performance per unit cost than the transistor.

TRANSISTORS

The extant types of transistors and their relative characteristics are compared in Table I. The grown-junction and alloy-type transistors were introduced at about the same time. The other types followed in the order listed.

The applications listed in Table I are the predominant ones. The mesa structure is sufficiently universal to be usable in almost any transistor application.

The comments on cost in the table are based on current levels with a guess as to what can be achieved in the next few years when the mesa types, in particular, have had an extended period of mass production. Current prices of the other older, more mature types would seem to be closer to the ultimate values than those of the mesas.

The predominate material listed for each type is more a result of circumstance than any compelling physical reason. No trend seems in evidence to change the current situation. A new material such as gallium arsenide will most likely make use of the mesa structures.

TABLE I — COMPARISON OF VARIOUS TRANSISTOR TYPES

	Grown Junction	Alloy	Drift	MADT	Mesa	Epitaxial Mesa
Fabrication:						
emitter	Grown	Alloy Dot	Alloy Dot	Alloy Dot	Alloy Dot or diffused	Same as mesa
base	Grown	——	Diffused	Diffused and micro-etched	Diffused	Diffused epitaxial layer
collector	Grown	Alloy Dot	Alloy Dot	Alloy Dot	Original Wafer	Original Wafer is substrate of low resistance
Maximum Practical Gain-Bandwidth, Mc	10–20	10–20	200–300	1000–2000	1000–2000	1000–2000
Collector Series Resistance	High	Low	Low	Low	High	Low
Collector Scored Charge	High	Low	Low	Low	Moderately High	Low
Power Capability	Low	Moderate	Moderate	Low	High	High
Ruggedness	Low to Moderate	Moderate	Moderate	Moderate	High	High
Applications	Low power, low frequency	Low to moderate power; low frequency	Low to moderate power	Low power	All	All
Relative cost	Moderate	Low	Low	Low	*Possibly lowest*	*Possibly lowest*
Predominant Material	S_i	G_e	G_e	G_e	G_e or S_i	G_e or S_i

Alloy, Drift and MADT

The fabrication differences or similarities are summarized in Table I and in Fig. 1 in terms of the electrode construction. Alloy dot emitters and collectors introduce very low series resistance and do not suffer appreciable charge-storage effects. These characteristics are generally desirable. The straight alloy process, however, is difficult to handle when the very narrow base widths needed for high frequencies are required. The drift transistor, with its diffused base and resultant drift field to speed up carrier motion, was introduced to extend the capabilities of the alloy transistor. The micro-alloy diffused transistor (MADT) introduces a still further refinement by using a precision etching technique to give very narrow base widths.

Mesa

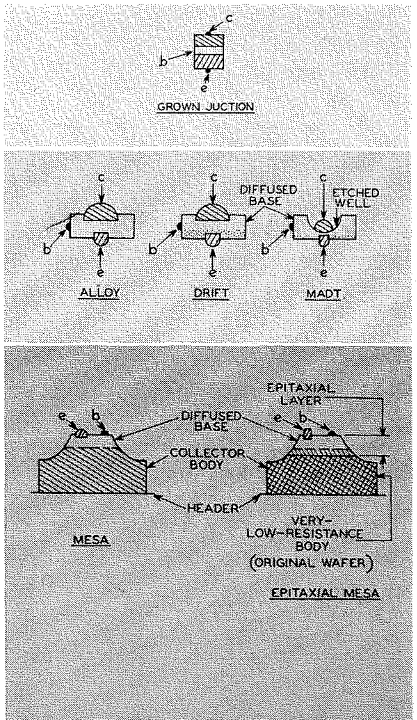
The mesa construction technique marks a distinct departure from the alloy approach and its various modifications. Maximum advantage is taken of the precision dimensional control possible with the diffusion process. The mesa structure has important advantages. Except for electrode lead attachment, still a troublesome problem, it is admirably suited to large-scale mass-production techniques. The structure is capable of very high frequencies and is inherently rugged and capable of large power dissipations. These desirable features are sacrificed to some extent by a higher collector resistance and increased collector stored charge. The latter is a disadvantage in saturated switching applications.

Epitaxial Mesa

The recently introduced epitaxial crystal growth technique promises to remove these disadvantages from the mesa transistor. In essence, epitaxial crystal growth is the technique whereby vapor deposition is used to build up a crystal layer upon a crystal wafer. The original wafer and the deposited layer constitute one single crystal, but the layer and the original wafer may be doped with different types and densities of impurity atoms. The electrical and physical dimensions of the layer are susceptible to precise control independently of the nature of the original wafer.

The epitaxial technique will clearly rival the older fabrication techniques in importance for many existing semiconductor devices as well as ones yet to be invented. Epitaxy offers an entirely new dimension in semiconductor-device design flexibility and, combined with the older techniques, will result in better all-round transistor performance as indicated in the table. Although the principle and practice of epitaxial growth have been known for some time, it was only early in 1960 that its immediate practical importance for an existing device was realized and exploited.

Fig. 1—Basic transistor types.



Grown-Junction

The grown-junction process represents a technology path which is quite distinct from that of the alloy and mesa types. This process was introduced as the first important practical method for making silicon transistors. Because of its early entry into the field, it has enjoyed widespread use. Performance-wise, however, it cannot compete with the newer mesa units or with the advanced alloy types for the basic reasons noted in the table. Thus, for new circuits the expectation is that the other types of transistors will dominate.

Characteristics

The listed values in Table I of the maximum practical gain-bandwith products are only approximations. Larger values already have or will be obtained, but these values are costly and their use at very high frequencies in competition with other devices, such as tubes, tunnel diodes, and varactor diodes, is questionable.

The collector stored charge usually completely dominates the base stored charge and is mainly of importance for saturated switching applications. The lowest values of the collector stored-charge time constant are obtained with the MADT type and have a value of the order of 15 nanoseconds. The best mesa units have somewhat higher values. Epitaxial mesa transistors are shortly expected to equal or closely approach the best values obtainable with the MADT type. Further improvements in the collector stored charge may be very difficult to achieve.

The power capability of transistors has increased steadily with the introduction of improved packages, silicon, better junctions, and better over-all design. The best high-power transistors, which are of the diffused-junction silicon type, can handle more than one thousand watts. Further improvements can be expected. From the standpoint of practicality the highest transistor power dissipation is now of the order of several hundred watts.

The frequency-power capability of transistors is shown in Fig. 2. All frequency-power combinations between

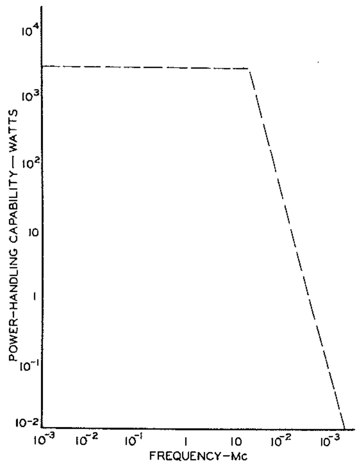


Fig. 2—Power-handling capability of transistors as a function of frequency.

the curve and the axes are possible. The slanted line indicates the approximate limits achieved by the best transistors known today. For example, some tens of milliwatts of r-f power have been generated at 1000 Mc and a few tens of watts have been generated at 100 Mc. Design optimization can be expected to improve these values somewhat. However, as frequency capability increases the transistor must get smaller in size, and this reduction decreases the power capabilities. Thus the physics of the situation sets an upper limit on the power-frequency capabilities which is not more than a few-fold removed from the best values already achieved, which lie on the slanted line. Introduction of a superior material, such as gallium arsenide, will improve the situation a few-fold more.

The device impedance level, which gets lower with increasing frequency, may, however, set a limitation on what can be achieved in an actual application. For example, in a transistor which can generate 10 watts at 100 Mc the input impedance is a few ohms. The horizontal line which sets an upper limit on the power-handling capabilities corresponds to the practical limit mentioned earlier.

At the other end of the power scale, low-power transistors will gain in importance, particularly for space applications and for applications where high component packing densities cause a heat problem. Some transistors with operating powers below 1 mw, which is substantially below that of conventional types, have already been announced.

The highest degree of ruggedness is most easily obtained with the mesa structures because the collector, which constitutes the main body of the device, can be soldered directly down to the header, as shown in Fig. 1. While the other structures are not so amenable to this construction, they are sufficiently rugged for most applications.

TUNNEL DIODES

The tunnel diode is a fairly recent addition to the family of active semiconductor devices. Like an ordinary switching diode, it is a p-n junction device. The tunnel diode features semiconductor material which is so highly doped with impurities that radically different electrical behavior takes place under forward bias, as shown in Fig. 3. Instead of the usual monotonically increasing current of the ordinary diode, a current peak, followed by a valley, occurs. The portion of the curve between the peak and valley currents provides a negative resistance which can be used for oscillation, amplification, switching, and other functions.

The voltage scale of the characteristic is fixed, with the entire range of interest appearing below one-half volt. At best, the scale can be expanded by a factor of about two by using a wide-band gap material like gallium arsenide. The peak current is increased by an increase in junction area and also by an increase in impurity density in the semiconductor material. The junction shunt capacitance varies directly with junction area and approximately as the square root of the impurity density. Accordingly, the highest-frequency diodes have a small junction area and very high impurity densities. As a rough rule of thumb, the gain-bandwidth product of the diode in cycles per second is numerically equal to the peak current in amperes divided by the shunt capacitance in farads.

Advantages

The advantages of the tunnel diode as a device are considerable. It is extremely simple and compact, and will be very inexpensive when manufactured in volume. It can be manufactured to close tolerances and, compared to a transistor, its characteristics are relatively unaffected by nuclear radiation, temperature, moisture, and other deleterious environments. Low noise with frequency capability into the microwave region is relatively easy to obtain. For the same frequency capability it can operate with substantially less power than the lowest-power transistors and thus can be useful where power consumption or heat dissipation is a problem.

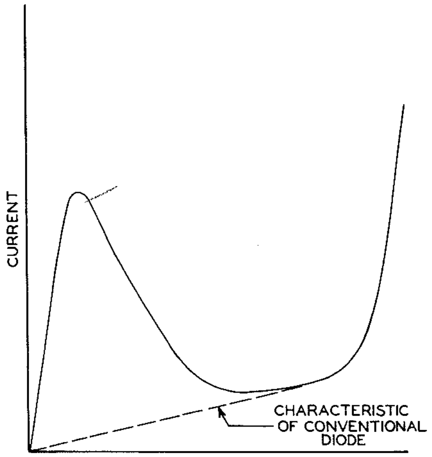


Fig. 3—Current-voltage characteristics of germanium tunnel diodes.

Disadvantages

On the other side of the balance sheet, the tunnel diode has some troublesome disadvantages. The most important of these is that it is a two-terminal device and, as such, suffers bidirectional signal flow and all the feedback problems that follow as a consequence. With respect to linear applications the dynamic range of the device is small so that it cannot easily handle a wide range of signal amplitudes, nor can it handle high powers. This limitation causes circuit complications for both linear and non-linear applications. For linear amplification, especially with cascaded stages, operation is most convenient at microwave frequencies where isolator techniques can be used to introduce unilateral behavior. For non-linear applications, such as switching in a computer, bidirectional behavior necessitates circuitry which is more complicated than that needed for a unidirectional device like a transistor. Computer applications may demand that diode and other component tolerances be held to at least ±5 percent.

Applications

In my opinion, the peculiarities of the tunnel diode will tend to restrict it to the application domains shown in Fig. 4. At low frequencies, it will be in competition with transistors for miscellaneous switching applications. In sheer mass of applications the transistor will unquestionably dominate up to frequencies approaching the microwave region. From here up into the microwave region, the tunnel diode will take over. Its small size, economy, modest power supply requirements, low noise, and general versatility will make it a strong competitor to tubes in this frequency range for small signal levels, both linear and non-linear. In many respects the tunnel diode is a "device man's device." The device, itself, is comparatively simple; most of the difficulty is in the circuitry.

Available diodes have the approximate ranges of parameter values noted in Table II. Future developments will

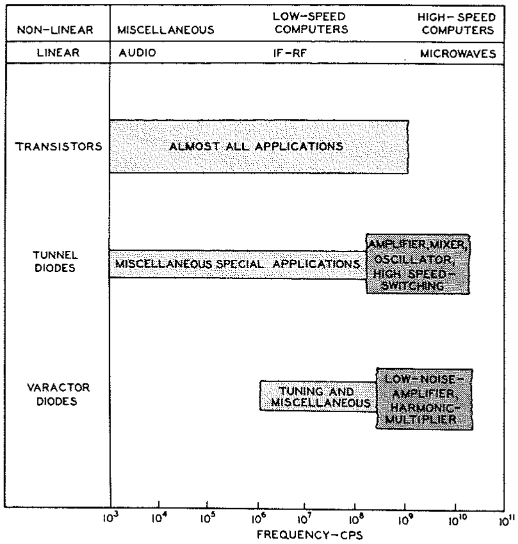


Fig. 4—Device application domains.

lead to reduced shunt capacitance, increased gain-bandwidth products, and increased temperature range. Much more information will be obtained about its stability under different operating conditions and ambients. Because of its simple construction the tunnel diode promises to approach design maturity much faster than the transistor.

VARACTOR DIODES

In essence, the varactor is a small, carefully constructed, p-n junction diode with very low series resistance r and shunt capacitance c. A very small r-c product, combined with operation restricted to the reverse part of the current-voltage characteristic, enables the diode to perform at frequencies well up into the microwave region. Amplification at frequency f_s can be made to occur when the reverse bias (hence junction capacitance) is modulated at the "pump" (power supply) frequency f_p, which is generally higher than f_s. Very low noise levels are possible because the dominant current across the junction is reactive and shot-noise components are absent. Reactive nonlinearity, without an appreciable series resistance component, enables the device to generate harmonics with very high efficiency. For example, conversion efficiencies as high as 23 percent for the third harmonic can be obtained.

Characteristics

Currently available diodes have characteristics which fall in the approximate ranges noted in Table III. The r-c cutoff frequencies will be extended in the future to values as high as 200,000 Mc, or even higher, especially with the new material gallium arsenide, which has generally more desirable characteristics than silicon for varactor diodes. During the time of manuscript preparation, the Semiconductor and Materials Division commercially announced gallium arsenide diodes with cut-off frequencies close to 200 kMc. Improved design will also result in higher values of the voltage exponent and allow the pump power to be minimized. For harmonic-generator service, diodes will be designed for an improved optimum between the cutoff frequency and the parameters c, V_o, and P_m, which determine the diode's power-handling capabilities. Power-handling capabilities of a few tens of watts in the microwave frequency range between 1000 and 10,000 Mc seem possible. In fact, harmonic power outputs of several watts have already been achieved near 1000 Mc.

Applications

The noise figures attainable with varactor diodes compared to other devices, including triode vacuum tubes and traveling-wave tubes, are shown in Fig. 5. Since noise figures are affected by the type of circuit and other application details, only the rough ranges could be given. After a few years of development, varactor diodes are giving a good account of themselves in the front end of various types of microwave receivers. Although they cannot give as low a noise figure as the maser, they and their supporting equipment and circuitry are much lighter, smaller, and more convenient to use, particularly in vehicles.

HIGH-TEMPERATURE OPERATION

The permissible temperature ranges of devices made out of germanium, silicon, and gallium arsenide are shown in Fig. 6. Germanium devices have an adequate temperature range for many applications, but for many other applications, particularly military, the greater temperature range of silicon devices is a necessity. This necessity stems from a combination of the required ambient operating temperature and the power dissipation in the device itself.

A number of applications, particularly in high-speed vehicles, require device temperature capabilities and margins of safety beyond those attainable by any present or future silicon devices. A great majority of these requirements will be met by a relative newcomer to the semiconductor materials field, gallium arsenide. As shown in Fig. 6, this material has a temperature range 200°C beyond silicon. Besides its obvious advantages at high ambient temperatures, this extra range should be useful in giving improved reliability over silicon devices operated close to their upper temperature limit. Another consequence of an improved temperature margin is

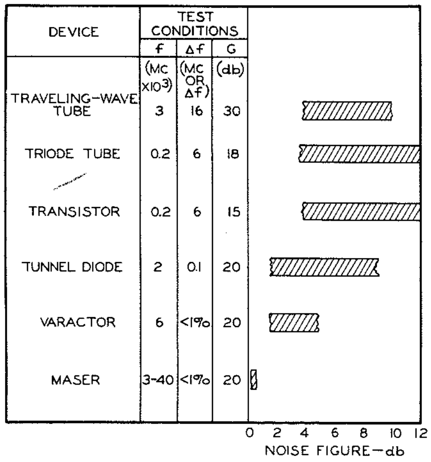


Fig. 5—Device noise figures.

TABLE II — AVAILABLE TUNNEL-DIODE CHARACTERISTICS

Material	Ge, Si, or GaAs
Peak current	1–50 ma ± 2% tolerance, or better
Peak-Valley Current Ratio	6–40
Shunt Capacitance	5–60 pf
Gain-Bandwidth Product	100–10000 Mc
Resistive Cutoff Frequency	200–8000 Mc
Temperature Range	−269–+150°C
Series Inductance	0.3–5 mμh

TABLE III — AVAILABLE VARACTOR DIODE CHARACTERISTICS

Material	Si or GaAs
r-c Cut-off Frequency	30000–150,000 Mc
Series Resistance, r	~1 ohm
Shunt Capacitance, c	0.5–3 pf
Maximum Reverse Voltage, V_o	5–15 volts
Series Inductance	~1 mμh
Voltage Exponent,* n	0.25–0.45
Maximum Allowable Power Dissipation	25–100 mw
Maximum Allowable Reactive Power	0.5–5 watts

* $C \alpha \frac{1}{V^n}$

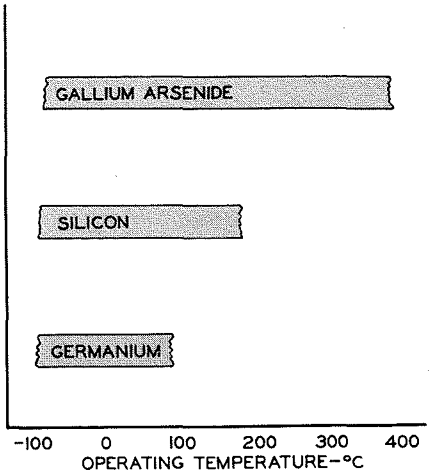


Fig. 6—Device temperature operating ranges.

that gallium arsenide devices should be amenable to higher packing densities and, also, have less dependence upon package size and design.

Another advantage of gallium arsenide devices is that, unlike silicon devices, they do not sacrifice frequency capability compared to germanium devices of comparable dimensions. Recently, a number of manufacturers (particularly RCA) have made gallium arsenide diodes available. In the next few years other devices, including transistors, will be available.

Silicon carbide offers the possibility of device operation in the extreme cases where the temperature is 600°C, or even higher. Unlike gallium arsenide, however, this material has decidedly inferior electrical characteristics at ordinary temperatures and so will probably be of interest only for the few special applications required at extreme temperatures.

RELIABILITY

Semiconductor devices have rapidly acquired a reputation for reliability, notably in large computers where the number of components is very large. In these applications, unit component failure rates, which might be low by other standards, can seriously disrupt the operation of the equipment. In such applications semiconductor devices have achieved a failure rate of the order of 0.01 percent per thousand hours operation per device. Certain military applications, however, now require reliability extending down to a failure rate at least ten times smaller. This latter rate is about equal to the level reached by some passive components. Consider that this means a failure, on the average, of one device per 100 million hours (approximately 10,000 years) of operation. Or, in other words, to observe one average failure in a month of operation would require a test sample numbering 100,000 units.

It is quite apparent that even to detect whether or not a device has high reliability is, in itself, an expensive and time-consuming task. The higher the degree of reliability desired the more difficult and expensive the whole operation becomes. Attempts to discover accelerated life-test procedures also require prolonged evaluation tests and, although valuable progress is now being made in these attempts, no adequately satisfactory accelerated life test of general applicability is yet available.

Accelerated life tests have a foundation in the fact that semiconductor device failure is mostly of a chemical nature (surface effects near junctions) and so should be accelerated by increased temperatures. These types of failures appear as increased junction leakage currents, increased noise, or as changes in the current gain of a transistor.

Attempts to improve semiconductor device reliability are based on some combinations of the following steps:

1) make design refinements of an existing device which promises, or has already demonstrated, good reliability;
2) exert meticulous control over the manufacturing process;
3) subject devices to a vigorous obstacle course;
4) carefully analyze each failure and vigorously pursue corrective measures;
5) pursue a comprehensive life-testing program.

The industry is very confident that the reliability needed, even in most extreme cases, can and will be achieved.

CONVENTIONAL DEVICES

Conventional diodes and rectifiers, not specifically treated here, will enjoy much of the sort of improvement and refinement described for the active devices. Diode switching speed will be improved along with reliability, uniformity, and general performance. Rectifier reliability, power capability, temperature range, and current and voltage ranges will be extended substantially in the years ahead.

CONCLUSIONS

The semiconductor device field is apparently entering a period of consolidation and refinement that will lead to a considerable improvement in over-all performance for a given cost. This development will have many important consequences. Semiconductor devices will find many new applications besides performing in old applications with greatly improved efficacy and reliability. Eventually, to some degree, these devices will incorporate portions of the adjoining circuitry. New devices, of which the tunnel and varactor diodes are an example, will outperform the transistor only in relatively specialized applications. New devices of greater general importance will, I believe, await new innovations in system organization and methods of handling digital information.

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MARKETING RCA MAGNETIC TAPE

by **E. O. WELKER, MGR.**
Marketing
Magnetic Tape Products
RCA Victor Record Division
New York City, N. Y.

THE RCA VICTOR RECORD DIVISION, which began audio magnetic-tape manufacturing in 1960 at Indianapolis, is responsible for magnetic-tape development and manufacturing operations as well as the over-all marketing activities for magnetic-tape products. The skills and capabilities of other RCA Divisions are also involved—domestic merchandising through the Electron Tube Division, and the foreign market through RCA's international activities.

EARLY MARKET STUDIES

Investigation of the advisability of going into the magnetic-tape business was started in 1953 and continued for several years. Market, engineering, and research studies all indicated that the magnetic tape business could be important to RCA. Some of the main considerations were: 1) RCA has the research and engineering capability to develop formulations and processes for a superior product; 2) RCA has had broad experience in the use of magnetic tape in audio, instrumentation and computer, and video applications; and 3) the market for magnetic tape is a rapidly expanding one likely to continue as more tape applications are developed. The size of the market (manufacturers selling prices) is currently estimated at $50 million, with a predicted growth in the next five years to the $100 million level.

Let us take a look at the various segments of the magnetic-tape market (and remember that we are talking in every case about blank or "raw" tape — *not pre-recorded tapes* which are marketed along with phonograph records by the RCA Victor Record Division).

AUDIO TAPE MARKETS

Magnetic tapes for audio applications vary in retail price from $.50 each to $25.00 each, and in length from 150 feet to 7200 feet; they are wound on plastic or metal reels ranging from 3 to 14 inches in diameter. All of the RCA audio tapes employ families of cellulose-acetate film bases (1.0 mil and/or 1.5 mil thick) and polyester film bases (0.5 mil, 1.0 mil, 1.5 mil, and 0.50 mil tensilized).

Most of the audio tapes are supplied in ¼-inch widths; however, ½-inch widths are employed in professional studio stereophonic recording. The users of RCA audio tape can be classified as follows: 1) home and semiprofessional (including school use), 2) professional recording studios and tape duplicators, and 3) radio stations.

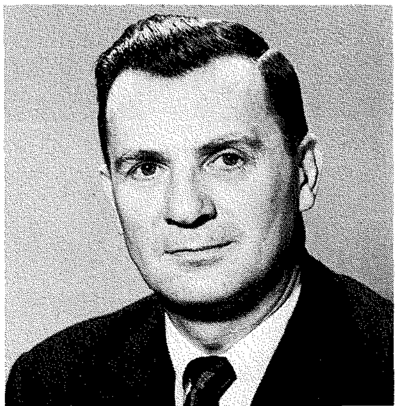
To service the domestic tape markets, the Distributor Products Dept. of the RCA Electron Tube Division buys tape from the RCA Victor Record Division and markets it through their established tube and parts distributors and photo-supply wholesalers. These distributors, in turn, sell to a variety of retail outlets.

In addition, RCA International Division sells RCA magnetic tape to its affiliated companies, distributors, and licensees; customers range from a government-operated radio broadcasting system in India, to a tape-recorder manufacturer in Denmark, to a recording studio in Venezuela. RCA Victor Limited, Montreal, Canada, markets RCA magnetic tape to its electron tube and semiconductor distributors, to their government, and other users.

RCA Victor Record Division Marketing also maintains a small sales force for certain markets—for example the U.S. Government, where special rigid specifications must often be met.

The quality requirements of audio-tape users vary widely. The home-recording market does not require as high a quality tape as that required by the U. S. Government (where application and environmental diversity require high standards) or for professional uses. A good-quality general-purpose tape, evenly wound of uniform width and free from surface defects, will serve the home recordist well. However, the professional users require a superior tape, wound to a precise tension, splice-free, and with magnetic characteristics to fit particular tape applications (high-output tapes, or tensilized polyester base tapes). Variance of tape characteristics from one reel to the next must be quality-controlled within narrow tolerances, and identification of each reel by lot number is required.

EDWARD O. WELKER, graduated from Temple University in 1936 with a B.S. in Commerce. He received an M.A. in Economics from Temple University in 1939. He joined the RCA Manufacturing Company in Camden in the Finance and Accounts Department to do long range economic forecasting and marketing research. He served in the U.S. Navy from 1942 to 1946 as a communications officer. In 1947, Mr. Welker joined the Record Division as manager of Sales Planning and Analysis, and later as a field sales representative from 1951 to 1954. In 1954 he came to the New York office of the Record Division as Manager, Popular Albums Artists and Repertoire, and in 1959 became manager of Product Planning and Market Development. In October, 1960 he was appointed to his present position. He is a member of Beta Gamma Sigma.



The commercial and government market for audio tape is highly competitive. To service the various customers, inventories are maintained by the Tube Division's Distributor Products Dept. in eight warehouses across the country. Competition is on the basis of quality, price, and service. The quality factor is most important to volume users. The most successful producers in the magnetic tape field will be those which maintain strict product standards and do the research and development work necessary to maintain high quality and to develop new and better tape formulations and processes.

INSTRUMENTATION, COMPUTER, AND VIDEO TAPES

An intensive research and development program has been underway for over a year to develop formulations and processes for a planned product line of RCA instrumentation and digital-computer magnetic tapes, and tapes for video use. Users in the instrumentation and computer field are constantly emphasizing the need for superior tapes that are error-free, uniform, strong, resistant to a wide range of temperature and humidity conditions, and with long storage life.

The use of instrumentation and computer tape has been expanding rapidly and will continue to expand with the extension of automation in industry and with the growing use of computers.

CONCLUSIONS

With the start of audio-tape production at the Indianapolis plant of the RCA Victor Record Division (see DeTartus, this issue), RCA is marketing an important new product line. The tape market is becoming increasingly competitive — a growth market, heavily dependent on research and development.

MANUFACTURING RCA MAGNETIC TAPE

by **D. A. DE TARTAS**
Tape-Formulation Laboratory
RCA Victor Record Division
Indianapolis, Ind.

Editor's Note: "Tape" has become a medium for recording many kinds of information for diverse applications—from scientific and commercial data through audio and visual material. Articles on these pages and elsewhere in this issue touch on some key engineering efforts in several RCA Divisions: **deTartas** and **Welker** (Record Division) on the new RCA product efforts of manufacturing and marketing raw audio magnetic tape; **Bick** and **Johnson** (Broadcast Division, IEP), and the cover, on video magnetic-tape recording; **Clayton** and **Hedlund** (Broadcast Division, IEP) on a new audio magnetic-tape recorder; **Hutter, Krittman,** and **Moore** (Astro-Electronics Division, DEP) on electrostatic recording; and **Isom** (DEP Applied Research) on a survey of several advanced recording devices and applications.

When RCA first became interested in the manufacture of magnetic tape in 1947, the Record Development and Design Laboratory in Indianapolis, a part of the RCA Victor Record Division, was assigned the task of studying the factors involved in tape manufacturing. These included base-film types, plastic binder materials, magnetic pigments, magnetic-lacquer processing and coating techniques, and physical and magnetic tests.

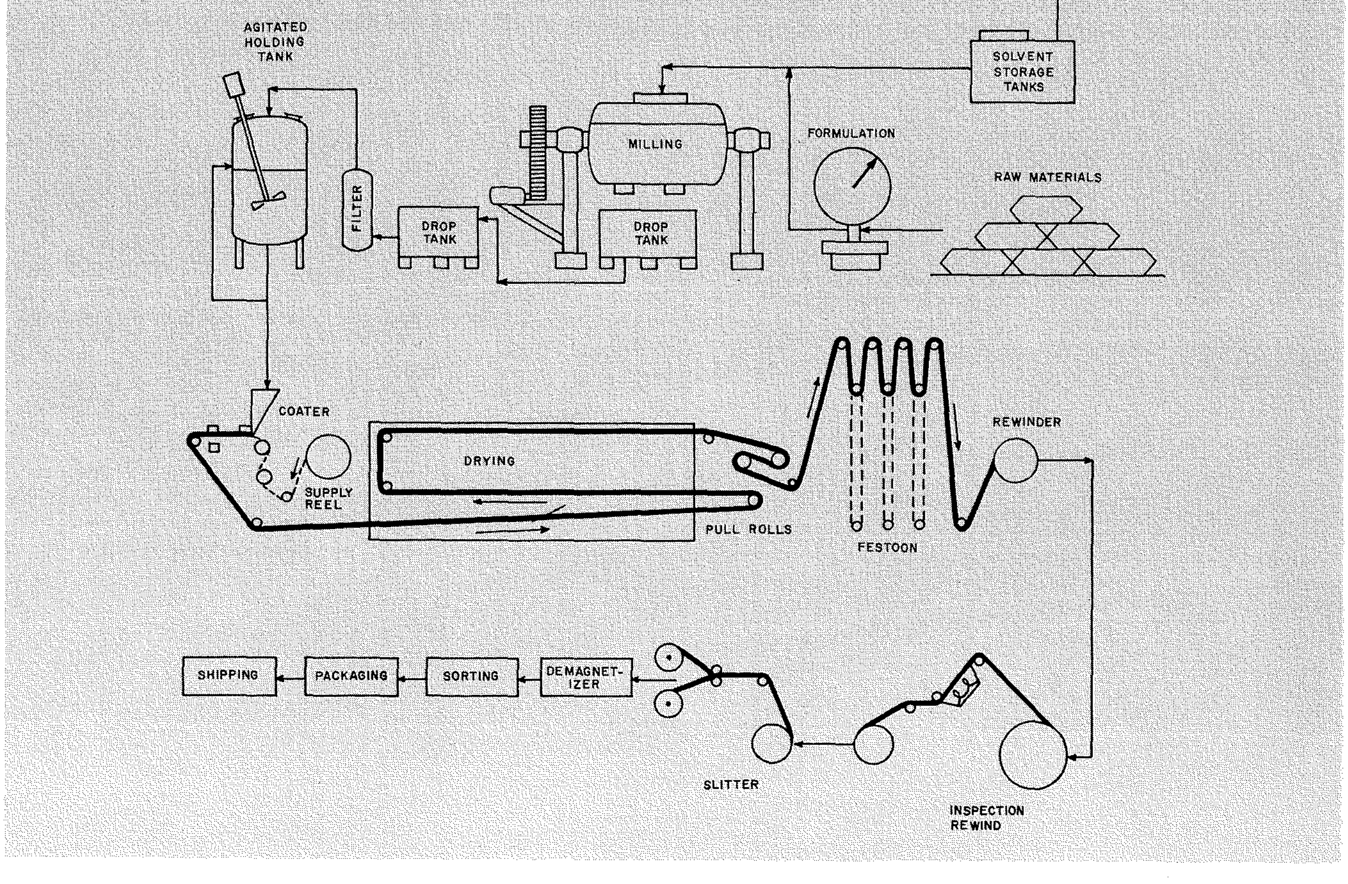
Interest in the manufacture of magnetic tape continued at Indianapolis and at the RCA Laboratories at Princeton, N. J. Early magnetic-lacquer formulation work was begun in Indianapolis with laboratory-scale processing equipment and hand-coating techniques. This work developed to the point where magnetic lacquer could be produced in gallon quantities and full-length rolls of tape coated at Princeton on a commercial-type production coater. Numerous trips between Indianapolis and Princeton were made to conduct coating tests. The Princeton Coater was then moved to Indianapolis and incorporated into the production plant then being established. A pilot-plant ball mill was purchased and placed in operation — actually the first piece of tape-processing equipment installed in what is now the Magnetic Tape Production Plant of the RCA Record Division. In one year, this plant has grown to the point where it is now capable of annually producing 1,200,000,000 feet of ¼-inch audio tape.

BASIC TYPES OF TAPE

There are four basic classes of magnetic tape in use at the present time: audio, computer, instrumentation, and video.

The familiar ¼-inch-wide *audio* tape is used primarily in the direct recording and reproducing of sound on equipment that ranges in quality from inexpensive home units to professional equipment.

Fig. 1—Magnetic tape manufacturing.



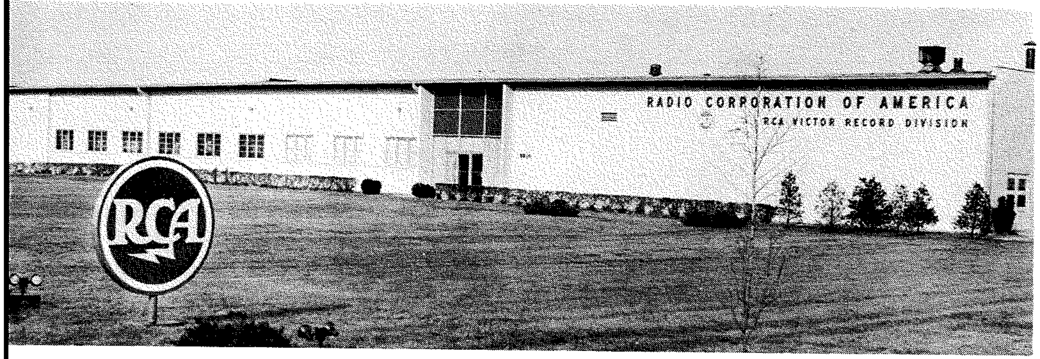


Fig. 2—Tape plant of the RCA Victor Record Division, 6800 E. 30th St., Indianapolis, Ind.

The *computer* classification encompasses a variety of tapes, varying in width from ½-inch to ¾-inch, for recording, storing, and reproducing data in equipment like the RCA 501 Electronic Data Processing system.

Instrumentation tape is designed to record and reproduce informational data of either the continuous-wave or bit type. It differs from computer tape in that the loss of a single bit of data does not necessarily result in the loss of an entire program. Computer tape, on the other hand, records single-entity bits which cannot be dropped without complete loss of the information concerned.

Video tape, 2 inches wide at the moment, is used for both black-and-white and color TV recording of both the video and audio program material.

The ¼-inch audio classification is currently being produced at the Indianapolis Tape Plant.

BASIC OPERATIONS IN MAKING TAPE

There are a number of steps in the production of a typical magnetic tape:

1) Selection and preparation of raw materials for a specific tape;
2) coating and drying;
3) inspection, slitting, demagnetization, and rewinding; and
4) final inspection, packaging, and shipping.

DONALD A. DE TARTAS graduated from Purdue University in 1946 with the B.S. Ch.E. He served in the Army Signal Corps from 1942 to 1946, and attained the rating of Chief Warrant Officer. In 1947, he started to work at RCA in the Record Development Laboratory in the Compound Development group of the RCA Victor Record Division. The original survey of tape manufacturing by him in 1947 laid the groundwork for the initiation of tape formulation and development work. Since 1958 he has worked with the tape formulation group at the Tape Plant in Indianapolis.

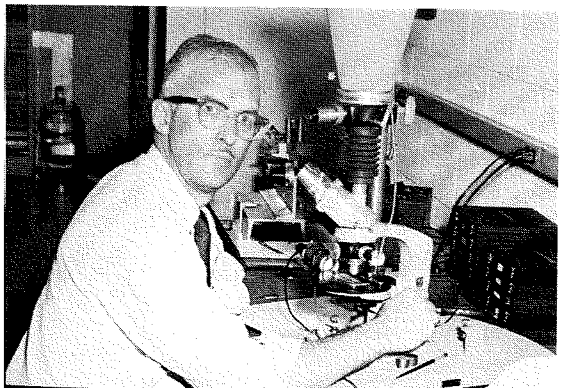


Fig. 1 is a schematic of the over-all process; Figs. 2 through 8 show the plant and various production steps.

Selection of Raw Materials

The end use of the tape determines its ingredients. The base, or *substrate*, can be a cellulose di- or tri-acetate, a polyester, or a polyvinyl chloride (PVC), depending upon the physical characteristics and ultimate cost requirements.

The base thickness is also specified by the end use. An extra-long-play tape would call for ½-mil polyester, and an inexpensive medium-quality tape might employ 1-mil cellulose acetate or PVC, while high-strength tape usually requires 1.5-mil polyester.

The magnetic pigment can be selected from a group of these materials for its physical and magnetic characteristics. Two pigments can differ widely in magnetic output, frequency response, print-through qualities, and ease of processing. These differences must be predetermined. The amount of pigment in the coating will, of course, have a considerable effect on the final magnetics of the tape. The binder resins that serve to hold the pigment in uniform suspension and cement it to the base film must be chosen carefully. A film-forming system must have good adhesion to the particular substrate chosen, or the magnetic coating will subsequently peel or crack.

Other characteristics, such as flexibility and drape, surface hardness, lubricity, and stabilization are sometimes controlled by introducing small quantities of modifying components into the oxide lacquer. They, of course, become a part of the final dry coating.

The solvents and diluents for the resinous binder system are chosen to produce a specific rate of evaporation.

Preparation of Raw Materials

The film bases are normally stored and coated under closely controlled temperature and humidity conditions, chosen to ensure a uniform product. Furthermore, each web of base film is inspected carefully for general appearance, cleanliness, loose wind, telescoping, soft spots, tension ripples, and other obvious defects before being sent to the coating room.

The preparation of the magnetic lacquer is one of the most critical steps of tape manufacturing. Any one of a number of different pieces of apparatus can be used, a ball mill perhaps being one of the most common. Essentially, this is a horizontal cylindrical chamber, motor-driven at a specific rotational speed about

Fig. 3—Laboratory development area.

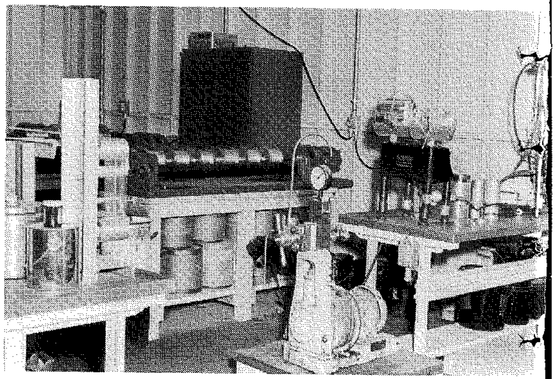


Fig. 4—Duct work on the coating machine.

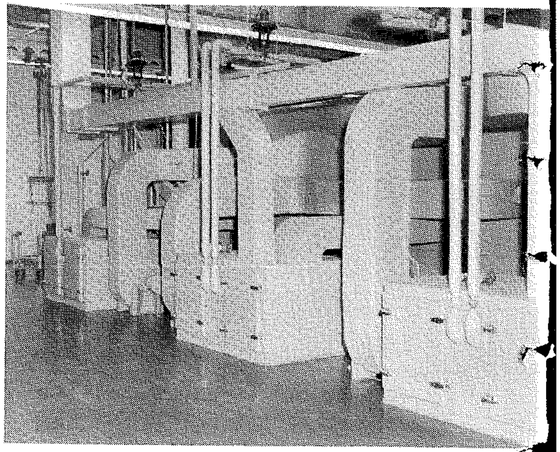
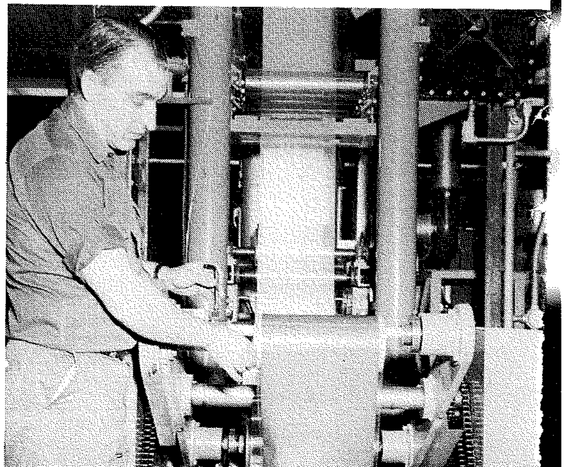


Fig. 5—J. Moore adjust roller mechanism on coating machine.



its long axis. The chamber is partially filled (45 to 55 percent) with hardened-steel balls about ½ inch in diameter. Ball charges can vary not only in total weight, but also in type and size of ball.

The individual components (resins, minor ingredients, magnetic pigment and solvents) are carefully weighed and put into the mill chamber. The mill is then rotated a specified number of hours. The cascading balls produce the impact and shear action necessary to provide a very finely dispersed suspension of the pigment in the vehicle at the end of the optimum milling period. A shorter milling cycle will result in a heterogenous slurry, which will produce a rough coating that yields poor magnetic properties. A longer cycle will conceivably damage the pigment particles and produce a tape having unsatisfactory magnetics.

The lacquer is removed from the mill to a drop tank, and then pumped through a primary filter (10 to 25 microns in pore size) to remove hard agglomerates, gels, and undispersed clumps. It then passes to a holding tank, which is under agitation at all times to keep the suspension uniform for the coating operation.

Coating and Drying

The coating and drying operation normally is conducted at a rate somewhere between 100 and 200 fpm. The web film, from 4 to 12 inches wide, is unwound and kept flat under tension with tension, idler, and drive rolls. The magnetic lacquer is passed from the holding tank through a secondary set of fine filters (from 5 to 25 microns in pore size) to remove any remaining minute heterogeneities. On the coater, the lacquer is then applied uniformly to the web.

To remove the solvents from the wet coating, the web is then passed through an oven where filtered, dry, hot air is passed, countercurrently. The conditions of temperature and volume of air per unit time are so adjusted that the web with its coating is dry upon leaving the oven. If the conditions are not correct and the coating is still tacky at rewind, it will stick disastrously. If the solvent is driven off too rapidly, the coating surface could be rough and blistered. Sometimes, two or more drying zones are used within the oven to moderate the rate of solvent evaporation, each having its own specific temperature range. During the coating and drying operations, controls are used to 1) ensure uniformity of coating thickness from one edge of the web to the other, and from one end of the roll to the other; 2) maintain an even and uniform linear speed of the web from unwind to rewind; and 3) minimize lateral creep during transit, so that the rewind roll will be as square as the supply roll.

Inspection, Slitting, Demagnetization, and Rewind

Each roll of coated web is given a visual inspection with transmitted light over its entire length. (Any defective areas are cut out and discarded during the next step.) The roll is then slit to the required width—audio tape is normally slit to a width of 0.246 ± 0.02 inches. The slit tape is wound on conventional plastic reels in the desired length, from 150 to 4800 feet depending upon the end use. Longer lengths are sometimes wound on single, or open-face hubs.

At this stage, the tape normally has picked up noise in the form of low-degree magnetization caused by the slitting operation and low-intensity stray magnetic fields. This interference is removed by passing each reel through a high-intensity demagnetizing field.

Fig. 6—Slitting machine cuts magnetic tape into 46 separate ribbons.

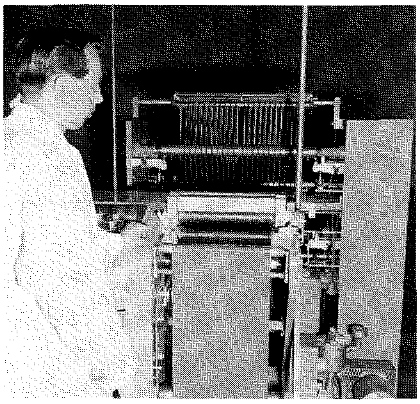


Fig. 7—R. Moore taking off 7200 foot hubs of ¼-inch tape from the slitting machine.

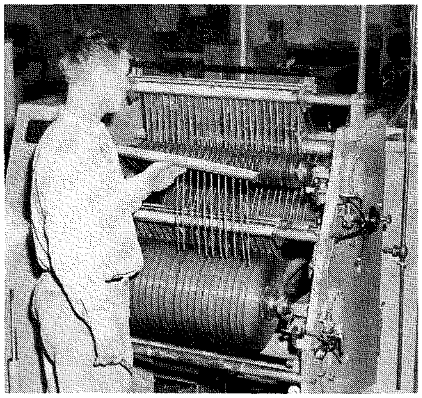


Fig. 8—N. Keeves checks a production-run sample of audio tape on the magnetic test console.

Individual reels with poor physical alignment are rewound so that the customer will receive reels of tape having flat, square, uniform winds.

Final Inspection, Packaging, and Shipping

Each reel or hub is then given its final physical inspection, put into its properly identified carton and boxed for shipment. The inspection, slitting, and packaging operations are all carried out in an area carefully controlled for temperature, humidity and cleanliness of air. Room dust and clothing lint are suppressed to a minimum level in order to produce a clean, uniform product.

Physical and magnetic control checks are made periodically throughout the entire manufacturing operation. Viscosity and temperature checks are made on the lacquer during its processing. Before a batch is dropped from the mill, a small-scale laboratory coating is made and tested for final physical and magnetic characteristics. A final coating-thickness check is made before any production scale coating is attempted. On the final product, periodic and spot checks are made. Depending upon the end use of a specific type of tape, the following physical tests may be made:

1) coating thickness and cohesion, and base adhesion;
2) surface hardness, roughness, and grain;
3) frequency of surface imperfections;
4) tensile and shock-tensile strength;
5) elongation, cupping, and curvature;
6) anchorage, and layer-to-layer or block adhesion.

The following magnetic tests could be made, again depending on end use:

1) peak recording bias;
2) low-frequency output and sensitivity;
3) frequency response;
4) print-through;
5) coercivity and retentivity, tape-noise-level, and erasing-field measurements.

CONCLUSION

The successful start of audio-tape production has launched the RCA Victor Record Division into an important new product line that has important market potential, as described by E. O. Welker in the accompanying article.

PROLOGUE . . .

. . . RCA's TV Tape Recording System

The RCA Television Tape Recording System, shown on the cover of this issue, provides a means of recording and playing back either color or monochrome TV signals simultaneously with program sound. The reproduction of both signals has a quality and fidelity which closely rivals that of the original program.

Since their introduction in 1958, these RCA systems have been well received by TV broadcasters. They are being used extensively for prerecording programs, as well as recording for short time delays to accommodate time-zone differences.

The RCA Television Tape Recorder records and plays back both audio and video signals on a single, 2-inch-wide magnetic tape in the form of magnetic patterns. The magnetic patterns on the tape, which is moving at a rate of 15 ips, are comprised of tracks registered as the tape and magnetic recording heads move with respect to each other. As may be seen in the accompanying article, the video record containing picture information is transverse to the tape while the sound record is along one edge. This information and the associated cue track and control track are recorded through the means of magnetic heads.

The video record, for reason of convenient geometry, is recorded in successive tracks by one of the four heads that are caused to scan the tape sequentially. These heads are mounted with equal angular spacing on the periphery of a small wheel which rotates about an axis parallel to the length of the tape. The precision and craftsmanship required in the manufacture of RCA's magnetic heads for TV recorders is comparable to that employed in making fine chronometers.

The adjacent article illustrates some of the problems encountered by engineering personnel in the Magnetic Heads Engineering section. Readers interested in an engineering description of the RCA Television Tape Recording System are referred to A. H. Lind's article *Engineering Color Video Tape Recording* in the Feb.-Mar., 1958, RCA ENGINEER.

MAGNETIC HEADS FOR TV TAPE RECORDING

by **J. D. BICK and F. M. JOHNSON**

Electronic Recording Products Engineering
Broadcast and TV Equipment Division
IEP, Camden, New Jersey

The heart of the broadcast TV tape-recording system is the head-wheel panel which transfers the video information to and from magnetic tape. The nature of the signals and their arrangement on the tape are governed by rigid standards to permit the interchangeability of tapes in the entire broadcast industry.

Fig. 1 shows the track standards adopted by the Society of Motion Picture and Television Engineers (SMPTE). The video records are arranged in a series of transverse tracks with a pitch of about 100. The control-track signal provides the capstan servo with the reference for registering the video records in playback and, in this sense, is analogous to sprocket holes on film. The video information is carried on a frequency-modulated sine-wave signal that varies in accordance with the video signal from 4.3 to 6.8 Mc (wavelengths of 360 to 230 microinches). The head-wheel rotates at 240 rps with a peripheral speed of about 1560 ips. The longitudinal motion of tape is 15 ips.

The tape-transport mechanism of the video-tape recording system with the magnetic tape in position for operation is illustrated in Fig. 2, while Fig. 3 is a photograph of the head-wheel panel as mounted on the tape transport and Fig. 4 shows head-to-tape contact.

VIDEO HEADS

The basic elements of the head-wheel panel are the four video heads (which are mounted in the head-wheel); the motor; the tone wheel and tone-wheel head, which supply angular and rate information to the head-wheel servo; the slip-rings and brushes, which connect the video heads to the video circuits; the tape vacuum guide, which controls the geometry of the tape in the scanning area; and the control-track head, which records and recovers the control-track signal on the tape.

Electrical Characteristics

The video heads are designed for a combination of low loss and long life. The magnetic structure of the heads consists of a coil wound on a trapezoidal core of ferrite and pole tips of alfenol. Alfenol was chosen, since it wears about three times longer than typical nickel-iron magnetic materials. However, the initial permeability of alfenol is only about one-fifth that of nickel-iron alloys and is off-set in the head by a very short flux path (.050 inch in each tip). The resistivity of alfenol is higher by a factor of three, which reduces the eddy-current loss. A hard metallic gap spacer is used to maintain a well-defined gap of 90 microinches and to reduce leakage flux in the gap.

Electrically, the frequency response must be substantially uniform from 4.3 to 6.8 Mc. Accordingly, the resonance of the head with the load capacitance (of slip rings, brushes, leads, and vacuum-tube input capacitance) produces a ledge in the frequency response in the range which otherwise would be falling off because of head losses. These losses divide between those that are frequency-dependent and those that are wavelength-dependent. The frequency-dependent losses are governed by the materials used and their geometry, and include eddy-current and hysteresis losses. Skin effect of flux in the alfenol tips is severe, and careful design has made the loss uniform for all portions of the recorded track.

The wavelength-dependent losses are associated with geometry of the gap, the recording field distribution, and azimuth error. Each of these losses is controlled in the head design. The gap length of 90 microinches is a design choice that resolves the shortest wavelengths with minimum loss, and at the same time gives usable output at long wavelengths. In general, the resolution of a magnetic head is obtained at the expense of sensitivity (or output) when impedance and pole-face depth are held constant. In other words, resolution and sensitivity behave in the same way as bandwidth and gain in amplifiers. The recording field distribution is a function of the recording current. In practice, the drive is adjusted for maximum recorded signal in the middle of the frequency band. Azimuth error, which degrades resolution, is controlled by mechanical tolerances.

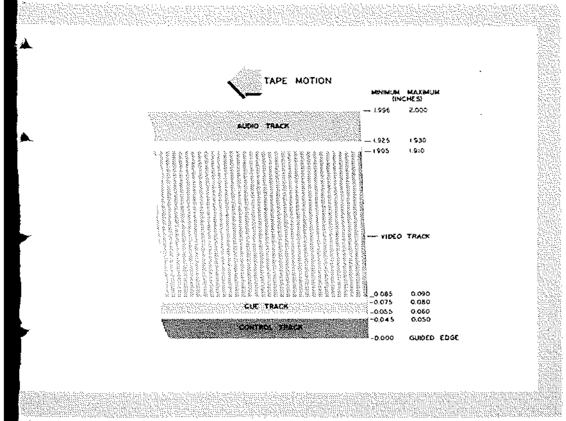


Fig. 1—Video tape track standards adopted by the SMPTE.

Mechanical Construction

The video heads are constructed as subassemblies before mounting in the head-wheel. The alfenol pole tips are inserted in a pair of brass clamping blocks and then cemented in place. After the pole sides are ground and the pole faces are lapped flat within 10 microinches, the gap spacer is inserted and the two mating blocks are clamped together with a No. 00-112 thread screw. The inner surfaces of the pole tips meet at a 90° included angle and receive the ferrite core, which is trapezoidal as viewed from the side, with the end surfaces lapped to an 89° included angle. The small coil seen in Fig. 5 is carefully layer-wound on the core with AWG #44 wire, whereupon this small subassembly is inserted into the clamping block-pole tip assembly with the matching surfaces adjusted for optimum contact. A rubber retainer holds the core assembly in place until the potting operation is completed. An aluminum-filled epoxy is used to seal the heads and to fix the position of its parts.

Mounting of Video Heads in Wheel

The heads are precision-mounted in the wheel to obtain the required timing and scanning geometry. The pole tip radius of rotation must be controlled within 0.0001 inch to achieve accurate tape-tracing geometry, as well as long life. The pole base radius (at the bottom of the pole faces) must be controlled within ±0.0001 inch for uniform head life and matched output. The heads must be coplanar within ±0.0002 inch for minimum loss due to mistracking and for minimum crosstalk, and the gaps must be correct in azimuth within 8 minutes of arc or 25-microinch displacement.

The highest precision is needed in the setting of quadrature in the head wheel between the gaps of the four heads. This is required for picture geometry when playing recorded tapes with head wheels other than those which made the original recordings.

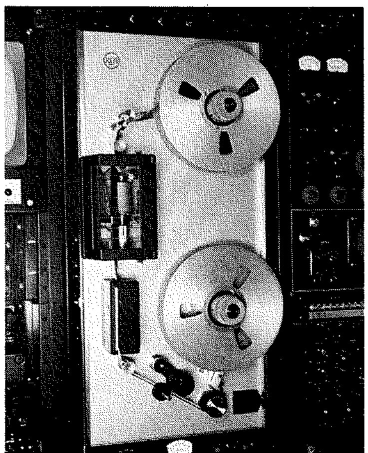
The TV raster, as derived from a taped signal, is made up of 16 horizontal bands of 16 or 17 TV lines each. Each of these bands corresponds to the scanning of one head in the wheel on one track on the tape. If the heads are not in correct quadrature, the bands are displaced horizontally, or sheared with respect to each other because of the relative timing errors. Vertical lines in the original signal are thus sheared in segments.

The quadrature is adjusted statically to within ±5 seconds of arc, which is equivalent to ±25 microinches on the periphery of the wheel. This represents a maximum time delay of ±0.016 μsec, while 0.01 μsec is regarded as the threshold of perceptibility. To correct the residual error of individual head-wheels and dynamic errors, delay lines are used in the system. The delay lines are also provided as a safety factor for playing back recordings which may have been inadvertently made under improper conditions. The accuracy of the four head positions in the head-wheel must remain for the life of the heads while the wheel is rotating at 14,400 rpm. Experience with adjusting screws showed that the required accuracy may be attained only momentarily and with difficulty. Epoxy-potting the heads fixed their position, but changing stresses during the cure cycle caused some serious shifting of position to occur; also, each head wheel equipped with adjusting screws was essentially a production fixture.

These problems were solved by providing clearance pockets in the wheel and devising an adjustable positioning fixture to hold the heads in place while epoxy is flowed through the clearances and cured. Because clearances are of the 0.005-inch order, the "shift" during cure is minimized. Of the four position tolerances which must be controlled, two are machined and two are adjusted.

The positioning fixture shown in Fig. 6 is essentially a flat disk cut so that four bars in the periphery are supported by a *T* web. The bars may be moved radially and circumferentially by adjustment of screws. The side of the fixture is flat within 0.00005 inch, so that when four heads are clamped with their sides to a *T* bar and the fixture is clamped to the reference side of the flat head wheel, an accurate tangency exists between the head-wheel reference plane and the side of each head block. The side of each head block is controlled in manufacture to be square within seven minutes to the pole gap plane and displaced parallel to the sides of the poles a uniform distance within 0.0003 inch, satisfying two position tolerances.

Fig. 2—Tape transport (also see cover).



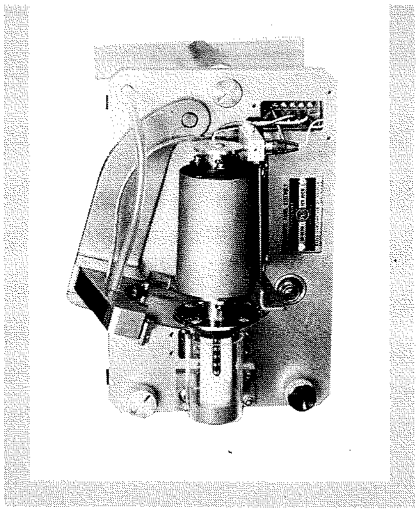


Fig. 3—Head-wheel panel.

The head wheel, shaft, and bearing assembly is then mounted in a dummy motor stator, oriented with its axis vertical on the stage of a toolmaker's microscope, and positioned so that the cross-hairs of the 200× microscope are at the desired radius from the axis of rotation (Fig. 7). The wheel is rotated until the side of a pole is focused squarely on the cross hairs. The protrusion screw in the fixture is then adjusted until the pole base coincides with the cross hair. Each pole is adjusted until all bases are equiradial within ±0.0001 inch from the axis of rotation. The head-wheel assembly and dummy motor then is transferred to a quadrature fixture (Fig. 8) which holds the dummy motor in a vertical position, while a 700× microscope positioned radially from the wheel is focused on the pole gap.

If the shaft is now rotated exactly 90°, the gap of the next head should coincide with the cross hair, or the head can be positioned by adjusting screws in the fixture until the gap does coincide with the cross hair. The 90° rotation is accomplished by placing a polished steel square on the top of and reasonably concentric with the head-wheel. The four faces of this square are mirror-polished and are square with respect to each other face within 0.2 seconds of arc. An auto-collimator is located radially from the head wheel so that it looks at the square; the light source in the collimator sends a beam toward the prism which reflects the light back into the collimator where it appears on a reticle as a cross hair. This reticle is micrometrically moveable so that the deviation required to align the reticle with the reflected cross hair image is measured in seconds of arc. Thus, the square and collimator become an indexing tool accurate to one second or less without adding friction or stress to the shaft, as would a mechanical indexing system. Each video head is squared within the accuracy of this system.

To preserve the head position, epoxy resin is now applied by drops and allowed to fill the space between the bottom of the pocket and the head block. The epoxy and cure procedure are selected for flowability, least shift, and maximum strength at 80°C. The present epoxy resin gives a factor of safety of ten.

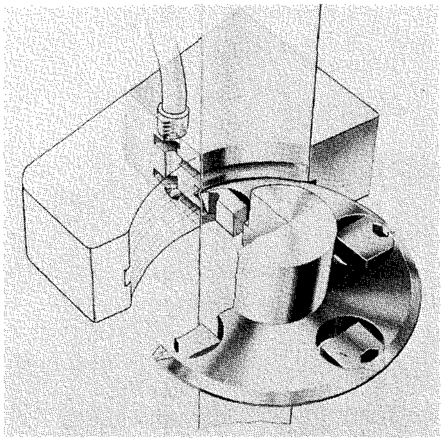


Fig. 4—Head-to-tape contact.

Wheel on Shaft

The rim of the wheel, during operation, may lightly touch the tape. Therefore, it is narrowed to a 0.010-inch-wide rim. The rim is hard-chrome plated and then is ground to the exact diameter and highly polished.

Since the rim may touch the tape, it must run true within 0.0001 inch total run-out, and the wheel must be interchangeable on the shaft to allow replacement. To reduce shaft warpage, it is machined from nitraloy steel and nitride-hardened before light finish-grinding on critical surfaces. The bearings are a selected push-fit to the shaft and are allowed only 0.00005-inch eccentricity.

Bearings

Bearings control the position of the axis of rotation. If the axis moves with respect to the tape, head-to-tape time-reference will change, and the picture jogs or scallops. If the axis moves with respect to the head wheel, the quadrature angles change and the picture becomes stepped. If the axis vibrates, all of these defects occur cyclically. Vibration over an amplitude of 15 microinches will be perceptible in the picture and is equivalent to a quadrature shift of 3 seconds of arc. If the vibration is half this great during the record operation and the tape is played back with the same head wheel, the defect will appear and disappear cyclically. The finest ball bearings are purchased to ABEC-7 Standards and selected for low noise. Very extensive tests have been made to specify a grease applied to the ball cages in the proper places and amounts to avoid picture jitter. Even the variations of viscous drag of oil or grease will cause jitter. Alignment of the inner races is controlled by a straight shaft and carefully fitted bearings. The alignment and position of the outer races is controlled by jig-boring the bearing seats in the motor stator at one operation for perfect concentricity and for locating the axis of revolution within ±0.0005 inch from reference buttons on the panel. To preserve this accuracy the motor stator is never removed from the panel.

Each assembly, as shown in Fig. 9, is balanced at full speed to maintain under dynamic conditions the precision established at static condition. The increase in life which balance gives the ball bearings is of secondary importance. The degree of balance achieved causes less than one microinch amplitude vibration of the rotating mass about its axis. The amplitude of vibration of bearing noise occurring at higher frequencies is much greater and must be filtered out of the balancer.

Motor

The head wheel motor, which is completed when the head-wheel shaft and rotor are inserted in the stator, is a three-phase hysteresis-rotor motor. It is operated asynchronously at a slip frequency of 120 cps below synchronous speed. In other words, the supply frequency is 360 cps and the rotational speed is 240 rps. The slip is controlled by the magnitude of the voltage supplied by the servo. The reference for both rate and angular position is the tone wheel, as shown in Fig. 9.

The smoothness of the rate of rotation of the motor is controlled by inertia, since the servo does not correct speed irregularities within one revolution. The motor runs more smoothly on controlled-slip conditions than it does when running synchronously because the magnetic unbalance is averaged by the slip condition.

Tape Vacuum Guide

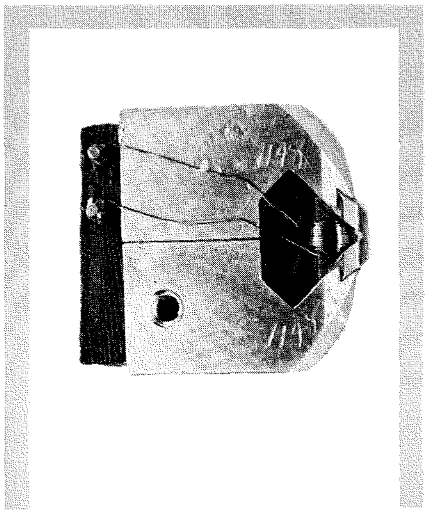
The tape vacuum guide holds the tape in a curve of uniform radius so as to bring it against the rotating heads.

The guide is adjustable, which permits precise positioning such that the center of curvature of the vacuum guide and the axis of rotation of the head-wheel are parallel to the base panel. In addition, the vacuum guide is movable along this plane toward or away from the head wheel under the control of a precise positioning servo. In this direction, the guide is positioned to hold the tape out of contact with the heads at all times except when actually recording or playing back signals.

When the recorder is in the *record* or *playback* mode, the guide is precisely positioned to establish the correct head-to-tape relationship. The precision of the tape guide is vital to the uniformity of the reproduced video picture. A groove in the guide allows the tape to be stretched over each head as it wipes across the curved tape; a new wheel with high pole-tip protrusion will stretch the tape more than an old wheel with low pole-tip protrusion. Thus, the curvature of the tape guide controls the time-velocity reference of the head to the tape, and the stretch of the tape cancels the velocity differences due to pole-tip protrusion differences. Irregularities in the tape-guide radius in the order of 0.00005 inch will cause visible variations in black-and-white pictures, and in color, substantial shift in hue.

If a color recording is made with a tape guide of uniform curvature and reproduced with a tape guide having a slightly nonuniform curvature, the phase will drift within the area scanned by each head and the picture will show hue shifts within each band.

Fig. 5—Video head.



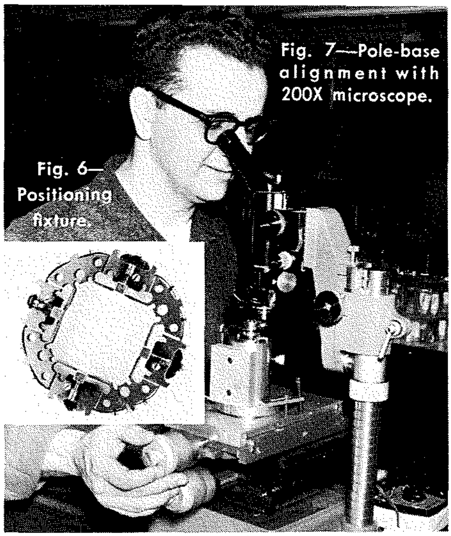


Fig. 6—Positioning fixture.

Fig. 7—Pole-base alignment with 200X microscope.

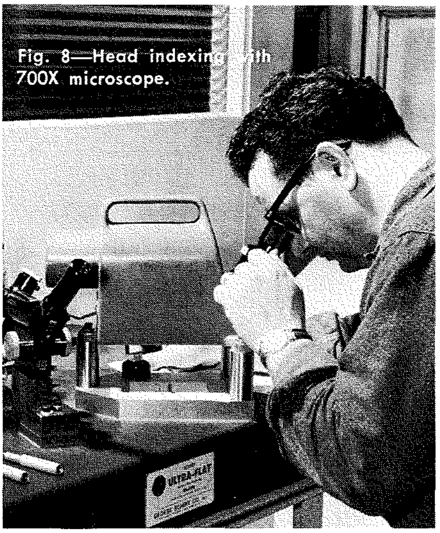


Fig. 8—Head indexing with 700X microscope.

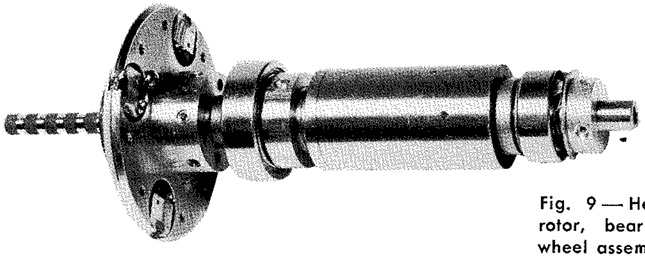


Fig. 9 — Head-wheel shaft, rotor, bearing, and tone-wheel assembly.

Slip Rings and Brushes

The slip rings and brushes connect the video heads to the external circuits. They are designed for low noise, long life, and low capacitance. The highly polished rings are coin-silver and have a diameter of 0.190 inch with a maximum run-out of 0.0005 inch. The brushes are carbon rods, spring-loaded in pairs to equalize the forces and to reduce the possibility of electrical noise. In practice, each brush is tested individually to determine that it is free from noise, resulting in highly reliable pairs.

Control-Track Head

The control-track head, a part of the head-wheel panel assembly, delivers information to the capstan servo for the proper tracking registration. The signals recorded and reproduced by this head include, in addition to a 240-cps tracking control signal, a 30-cps frame pulse for splicing and precision playback.

The control-track head is precisely located with respect to its standardized position on the tape and to the distance from the center line of the video heads. It is located close to the video heads to minimize tape stretch outside the control of the capstan servo loop.

Tone Wheel and Head

The tone wheel and the associated head deliver information to the head-wheel servo to indicate the angular position and rate of rotation of the head wheel. The tone wheel head has a permanent-magnet core, coil, and coaxial gap, while the tone wheel provides a variable reluctance to the external field of the head by means of a slot in the periphery of the wheel. The angular position of the slot is located precisely with respect to the video heads.

NEW DEVELOPMENTS—AIR BEARINGS AND IMPROVED POLE-TIP MATERIALS

A head-wheel panel utilizing air bearings in the head-wheel motor is now in production. Air bearings exhibit a marked improvement over ball-bearing assemblies in that vibration and rotational deviations are reduced. Only the rotational-speed frequency is present, and its amplitude is reducible by balancing. The balancing machine, although it filters out other frequency signals, is normally distracted by the ball-bearing noise spectrum. Use of the air-bearing assembly will result in a finer balance—desirable in the air-bearing assembly to achieve quadrature angle control, and not to increase bearing life, which is unlimited. Although the shaft of the air bearing is stiff, as might be desired in the ball-bearing assembly, the supporting pad of air acts as a soft spring, making the position control of the axis of rotation very soft. In use, this has not been detectable as a defect even when excessive pole-tip protrusion and excessive tape pressure were combined. It is therefore concluded that load on the bearings resulting from the tape pressure is insignificantly light.

Under the head-to-tape pressure required for intimate contact between the magnetic-head pole tips and magnetic oxide, and with the high head-to-tape velocity that exists, abrasive wear of the pole tips occurs. The useful life of the video magnetic heads is therefore limited. The principal reason for using alfenol, as was mentioned earlier, is its high resistance to abrasion. A continuing search for better pole tip materials has brought single-crystal ferrites, yttrium-iron-garnet (YIG), and other materials related to alfenol (aluminum-iron alloys) under study. A special alloy has been found that, from tests currently being made, not only possesses better wearing qualities than alfenol but also, better magnetic characteristics.

SUMMARY

The requirements of video tape recording have resulted in a specification for the head-wheel panel which pushes the limits of the art in many directions.

The final analysis is observation of the reproduced TV picture which contains, for thousands to see, a magnified display of the residual errors in the head-wheel panel assembly. Thus, many have witnessed the narrowing of tolerances and the increasing level of performance in TV tape recording today.

J. D. BICK has attended the Universities of Wisconsin and Chicago, and the RCA Institutes. Prior to joining the engineering staff at RCA in 1948, he worked on microphones, electronic pianos and other consumer products, and bomb ballistic measurements in the U. S. Air Force. At RCA, Mr. Bick was engaged in the design and development of broadcast audio tape recorders and TV tape recorders until 1957, when he transferred to the new Magnetic Head Engineering group. His work with this group has been centered on TV magnetic recording heads and magnetic heads for EDP tape stations. Mr. Bick has been granted three patents and has had articles published in the *Audio Engineering Society Journal* and the *SMPTE Journal.*

F. M. JOHNSON received his BSME degree from Pennsylvania State College in 1938. He was employed until 1948 by the Universal Camera Corporation in the design of cameras, projectors and lens-building machines for binocular optics. From 1948 to 1950, Mr. Johnson did engineering design of automotive replacement switches at the Ideal Corporation, Brooklyn, N. Y. At the International Resistance Corporation he was engaged in the design of deposited carbon resistors, and machines and tools for metal-film resistor production until 1957. During that year he joined RCA in the Airborne Fire Control section from which he transferred late in 1957 to the Magnetic Head Engineering group. Here he participated in the design and development of the head-wheel panel of the TV tape recorder and is presently assisting in the production phase of the same unit.

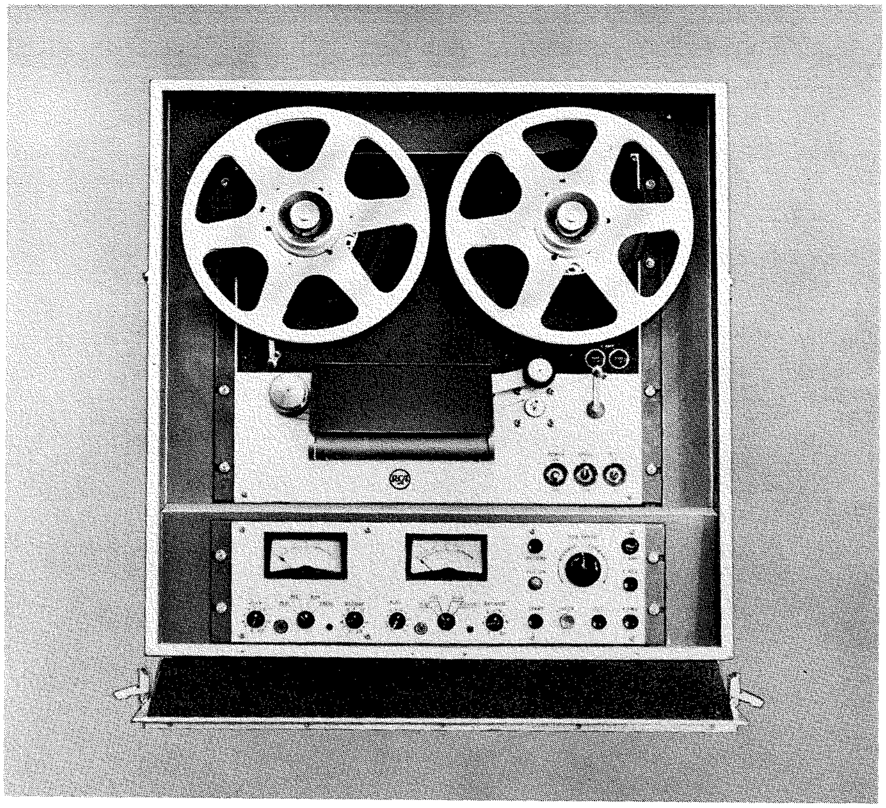


Fig. 1—Front panel of the RT-21A. The control panel at the bottom is in three sections: left, monaural record-playback module; center, space for a duplicate module for stereo operation (shown installed here); right, operating controls. The controls on each record-playback module include record level, playback level, a headset jack, and bias adjustment and meter function selector to monitor, playback, record, bias, and erase signals. Pushbuttons and toggles at right are operating controls (start, stop, cue, speed, etc.)

THE RT-21A TAPE RECORDER

... A New Professional Audio Instrument of Advanced Design

by **R. W. CLAYTON and L. V. HEDLUND**
Electronic Recording Products Engineering
Broadcast and TV Equipment Division
IEP, Camden, N. J.

After an absence of several years, RCA is back in the market with a new professional audio magnetic-tape recorder. The RT-21A Professional Audio Tape Recorder, shown in its two-channel form in Fig. 1, is a high-quality recording and reproducing instrument. It utilizes ¼-inch-wide magnetic tape and is capable of recording audio frequency range (30 to 15,000 cycles per second) signals. Transistors are used throughout the electronic circuits; in mechanical respects, it is also of advanced design.

DESIGN CRITERIA

The objective of this design was to achieve a competitive-cost recorder which in operating convenience and performance would be superior to the broadcast-quality recorders presently available. This required that the unit have stabilized electronic functions, high signal-to-noise ratio, good frequency response, and low flutter and wow. Another prime consideration was easy, rapid tape threading and ready access to all components. The RT-21A utilizes dual-half-track or full-track, as well as the quarter-track heads, thus allowing stereo and monaural applications. Provisions have been made for an optional fourth head.

The basic tape recorder is supplied in two sections: the tape transport panel, and the amplifier module and control panel assembly. Both can be mounted in a standard 19-inch wide rack, console cabinet, or portable carrying case. A remote-control unit containing duplicate control-chassis functions (less cueing mode) is also available.

TAPE TRANSPORT SYSTEM

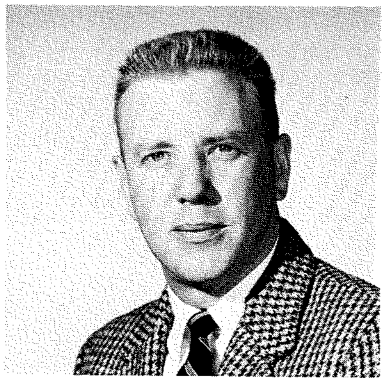
As mentioned above, low flutter and wow were of great importance in the design of the recorder. The reel motors, used to supply the required constant tape tension, were therefore designed to provide a constant torque at low speeds.

Reel Motors

To accomplish the desired low flutter and wow, the supply reel motor must have a constant torque in a direction opposite to that of the moving tape to provide the required tension in the tape for proper contact pressure between the magnetic heads and the tape. An engineering model of the magnetic heads and associated magnetic tape is illustrated in Fig. 2. Although the supply reel motor provides nearly constant torque, there are other factors contributing to the flutter and wow. In order to minimize these variations in tape speed, a tape-driven stabilizer is located directly under the supply reel motor. This may be seen both in Fig. 1 and Fig. 3 The high inertia of the flywheel, when combined with low friction of the preloaded, precision ball bearings, results in stabilization of tape speed variations. The associated supply tension arm minimizes tape slippage over the stabilizer head.

Although the tape transport is designed to handle both 7-inch and 10½-inch reels, reels of the same size allow the most satisfactory operation of the brakes. Low concentric hub and knob assemblies were designed for mounting either the 10½-inch or 7-inch reels to the supply and take-up reel motor shafts.

R. W. CLAYTON received the B.S. degree in Mechanical Engineering from the University of South Carolina in 1957. After a short period of employment with RCA, he entered the U. S. Navy in which he served as an Engineering Officer. Upon returning to RCA in 1959, Mr. Clayton rejoined the Specialized Training Program, and after completion of it was assigned to the Electronic Recording Products Engineering group. There, he is currently working on the mechanical design of audio tape recorders.



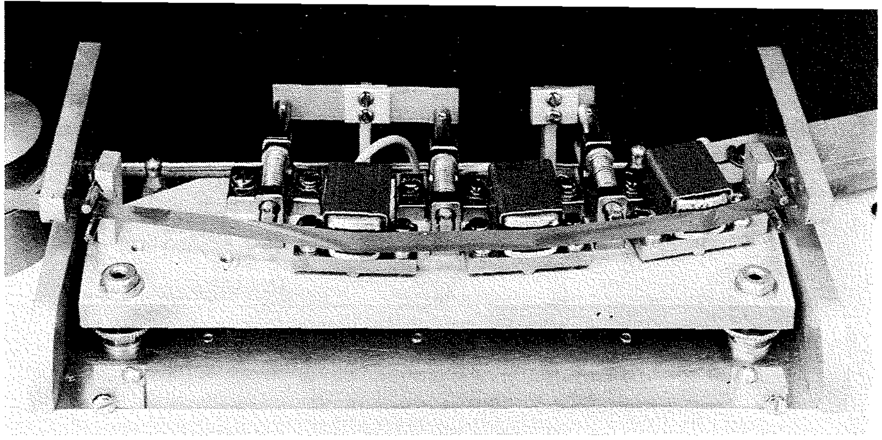


Fig. 2—Close up of tape heads (cover at center of Fig. 1 removed). The three heads shown are normally supplied with the equipment, and provide dual half-track recording and erase, as well as dual half-track or full-track playback. Space is allowed (left) for an optional fourth head for other applications.

With the hub-and-knob, collet-type assembly in place, the 10½-inch reel can be slipped on and off easily without removing any part of the assembly, while for use of the 7-inch reel, the hub is not required.

Capstan Motor

The capstan motor is designed to provide maintenance-free operation. This hysteresis-synchronous motor has permanently lubricated precision ball bearings of quality compatible with the low flutter requirements of the machine. The motor operates from 115 volts-ac, 60 cycles (the unit can also be supplied for 50-cycle operation) with a synchronous rotor torque of 12 oz-in minimum. The capstan shaft is made of stainless steel with a hard-chrome plate to provide a hard, smooth surface for tape handling. All motors are balanced under 0.004 oz-in through the speed range of 0 to 1000 rpm.

The capstan shaft drives the tape directly, using 24 poles at 3.75 ips and 12 poles at 7.5 ips. This provides optimum performance, particularly at 3.75 ips where flutter and wow are normally excessive with motors having fewer poles and speed-reduction mechanisms. As a result, the RT-21A will handle ¼-inch-wide tape on 7-inch or 10½-inch reels with flutter and wow of less than 0.25 percent at 3.75 ips, 0.15 percent at 7.5 ips, and 0.1 percent at 15 ips.

Brake System

The initial brake design of the RT-21A Tape Recorder was partly electrical and partly mechanical. The braking system worked satisfactorily, providing there was electrical power to the machine. The brakes depended on a back electromotive force in each reel motor for part of the braking; if this force was lost, the mechanical braking alone did not supply the proper braking differential and the machine would throw tape loops. Thus, the electrical braking was abandoned, and a completely new, mechanical brake was designed to operate with one solenoid to supply the brake release. In this case, if electrical power was lost, the solenoid would be de-energized, with the mechanical brakes stopping the tape immediately with no tape loops.

The RT-21A braking system (Fig. 4) was designed to provide an inexpensive, maintenance-free brake which applies greater braking torque to the supply reeling hub than to the take-up reeling hub. Simple construction resulted in fewer parts than known braking mechanisms of the type which provide differential braking action.

The brakes utilize compliance loops combined with conventional spring-biased band-type brakes. The bands are arranged in mirror-image fashion on the two brake hubs and are interconnected by a floating rigid-bar assembly.

When the brake bands are brought into contact with the brake hubs, the rotational energy of the brake hub,

L. V. HEDLUND was graduated from the University of California, Berkeley, Calif., in 1959 with the degree of B.S.E.E. That same year he started with RCA in the Specialized Training Program, which took him to IEP in Camden, DEP at Moorestown, and AED in Princeton, N. J. In these assignments, Mr. Hedlund worked on tape machines, microwave, and communications equipment, respectively. Since being assigned to IEP's Electronic Recording Products Engineering group in 1960, he has been active in the design and development of both audio and video tape equipment. Mr. Hedlund is a member of the IRE.

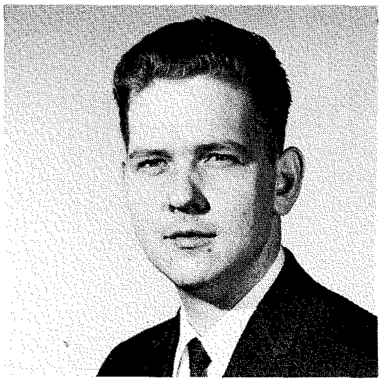
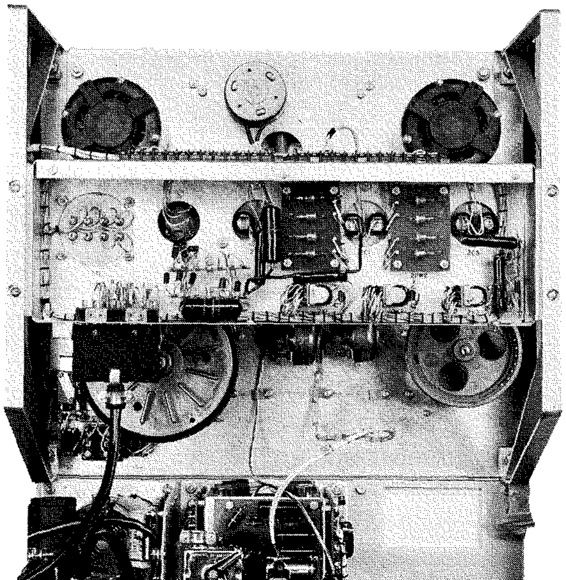


Fig. 3—Rear view of the RT-21A. Bottom center: self-contained, removable record-playback (amplifier) module; space at right is for duplicate module. Bottom left: the control module. Transistorized, printed circuits are used.



which supplies the tape, is transmitted from the brake band associated therewith through the rigid-bar assembly to the other brake band, which operates with the brake hub that takes up the tape. The band assemblies associated with the reeling brake hubs that supply and take up the tape expand and contract so that the bands and the interconnecting bar assembly are displaced. The brake band associated with the reeling take-up brake hub is self-relieving, since in its displaced position less braking is applied; the brake band associated with the supply brake hub is self-energizing in its displaced position, since more braking is applied. Differential braking action is thus produced. As greater braking torque is applied to the reeling supply brake hub than to the reeling take-up brake hub, proper tension is maintained in the tape to prevent the throwing of tape loops.

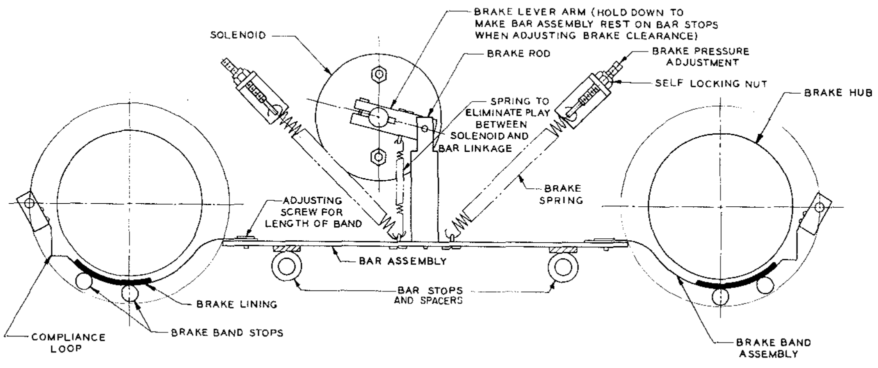


Fig. 4—Braking system (view from rear).

When the tape is emptied from the supply reeling hub or when the supply reeling hub is stopped, forces are no longer supplied through the rigid bar assembly to the brake band associated with the take-up reeling hub. Accordingly, the supply hub brake is not displaced toward the take-up reeling hub and full braking torque is applied to the take-up reeling hub. The take-up reeling hub is then rapidly brought to a stop. This minimizes the whipping and tearing of the end portion of tape as it is reeled onto the reeling take-up hub.

CIRCUIT DESCRIPTION

The electronic circuits are completely transistorized and mounted on printed circuit boards. Each record-reproduce unit and each control unit is self-contained on a modular chassis and are called the *Amplifier* and *Control* module, respectively. For service, the modules can be removed from the recorder with little effort (see Fig. 3).

Power Supply

The control module contains the transport function, which will be discussed later, and a —30-volt regulated dc supply which supplies power to the circuits in the amplifier module. The supply consists of a solid-state bridge rectifier, filter capacitors, and regulator. The ac power is obtained from the secondary of the main power transformer in the relay chassis on the transport. The regulator uses four transistors and one voltage-reference Zener diode.

The operation is of the usual series-regulator type: The output voltage is compared to a voltage reference, and the error voltage is amplified by dc amplifiers. This in turn causes an increase or decrease in the voltage drop across the series regulator in a direction to oppose a voltage change across the output terminals.

Recording Circuits

The record channel consists of three printed-circuit boards, a gain control, two transformers, an equalization network, and a metering circuit. One transformer is used for matching either a 150- or 600-ohm line to the input preamplifier.

The first and second printed circuit boards are identical amplifiers and are connected via a gain control on the front panel. The preamplifiers use a low noise n-p-n transistor in the first stage and a p-n-p transistor in the second stage in a direct-coupled, second-collector-to-first-emitter, negative-feedback pair. This feedback, together with local emitter negative feedback, provides for good temperature and gain stability, along with good transistor interchangeability.

The third printed circuit board is a unity-gain, parallel-connected series amplifier using four transistors; it is connected to an output line-matching transformer. The record amplifier will deliver 100 milliwatts into 600 ohms. The output transformer also drives a parallel RC equalization network, bias trap, and the record head. The RC equalization network provides for a constant record current plus the necessary peaking that compensates for the high-frequency losses in the recording process. This equalization is changed automatically when the tape speed is changed by changing the tape selector switch to one of its two positions.

An 80-kc bias and erase oscillator is also included in the amplifier module. One output of the oscillator is fed through a capacitor which resonates with the inductance of the erase head to provide for maximum erase current. The other output is fed through a large series resistor directly into the record head where it is added to the audio signal being recorded. The oscillator and record amplifier are isolated from each other by an 80-kc parallel-tuned LC bias trap between the output of the record amplifier and the output of the bias oscillator.

Playback Circuits

The playback channel (Fig. 5) consists of the playback head, three printed-circuit boards, a gain control, a transformer, and a metering circuit. The head is connected between the bias network and the base of the low-noise n-p-n input stage of an equalized preamplifier (Fig. 6). The dc current through the head is less than 15 microamperes and does not result in magnetization of the head or erasure of a recorded tape. Other than this difference in the input connection, the design of the preamplifier is of the same design as the two preamplifiers in the record channel. This type of input connection eliminates loading of the head by the relatively low resistance base bias network. The input stage itself does not appreciably load the head even at the high frequency end of the spectrum due to the dual voltage feedback which results in a high input impedance. The feedback network also contains the equalization necessary to reproduce a standard NAB recorded tape.

The second printed-circuit board is a three-stage feedback-voltage amplifier. The first and second amplifier boards are connected via a gain control on the front panel. The three-stage amplifier is of the capacitance-coupled type, with each stage having its own bias network.

Local feedback is used in each stage combined with a feedback network from the third to first emitter. This type of feedback and biasing provides for good temperature and gain stability along with good transistor interchangeability. The third board is identical to the third board of the record channel, as is the output transformer; therefore, the playback channel will also deliver 100 milliwatts into 600 ohms.

The output of the record and playback channels can be monitored by a VU meter on the front panel by selecting the desired output with the selector knob beneath the meter. Provisions have also been made so that the bias and erase current can be monitored with the same VU meter and knob.

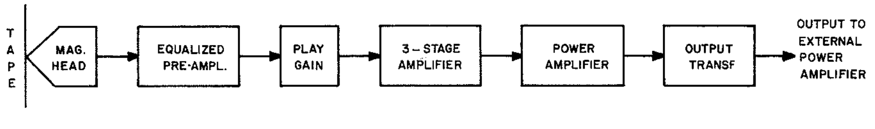


Fig. 5—Simplified diagram of playback circuits.

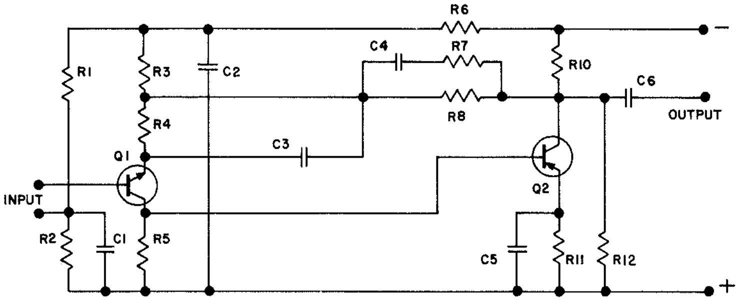


Fig. 6—Equalized preamplifier.

Magnetic Heads

The magnetic heads (Fig. 2) were designed to provide ease of manufacturing without sacrificing frequency response. The record head has a 500-microinch gap for both half-track and full-track heads. The two playback heads have a 100-microinch gap. Also available is a playback head with a 200-microinch gap for 7½ and 15 ips.

The distance between the centers of all the head gaps and the head plate on which the heads and tape lifter assemblies are mounted is a controlled, fixed dimension. Inasmuch as the tape path is determined by the two take-up tension arms, the head-plate is adjusted to provide alignment of tape over head gaps by three knurled nuts located behind the head-plate. After this adjustment is made it should never have to be changed; the only adjustment thereafter to the heads is azimuth. Azimuth adjustment is accomplished by two screws, one on each side of the head mounting block. These screws provide a fine rotating mechanical adjustment to the heads to obtain maximum efficiency.

OPERATION

The control panel (Fig. 1) features an interlocked record operation. Magnetic tape may be easily threaded in the RT-21A Tape Recorder without removal or movement of the head cover. Tape guiding and lifting is accomplished with small sapphire rods. Solenoids will lift the tape away from all magnetic heads whenever the machine is in the fast-forward or fast-reverse mode of operation to minimize head wear by tape abrasion. Quiet operation of the tape lifters is achieved through the use of nylon and stainless steel for the two impact surfaces. Air damping was provided for slow release of the pinch roller from the capstan shaft to prevent excessive noise. The continuously variable cue speed permits the operator to listen to the audio during final cueing. The tape is lifted off the erase and record heads during the cue mode.

Three safety features are included in the equipment: fail-safe braking system, tape break switch, and record interlock. The fail-safe brake will be engaged when a power failure occurs, thus avoiding tape breakage or spillage. Should the magnetic tape break, the tape-break switch will cause the brake solenoid to drop out, thereby stopping the reel motors. The record interlock system requires that the tape be stopped before the record function may be started. Depressing any other button except *start* after the *record* button will also interrupt the record function.

Another relay interlock in the recorder prevents selection of a low-speed mode after a high-speed mode without first going through the stop mode. This prevents breakage or spillage which would result if the start mode could be selected after the fast-forward, fast-reverse, or cue mode. The speed selector switch, in addition to changing the number of poles used in the capstan motor, also selects the proper equalization of the record and playback amplifiers. The result of the various interlocks is a practically fool-proof operation of the tape recorder.

The frequency response and signal-to-noise ratio of the RT-21A are shown in Fig. 7.

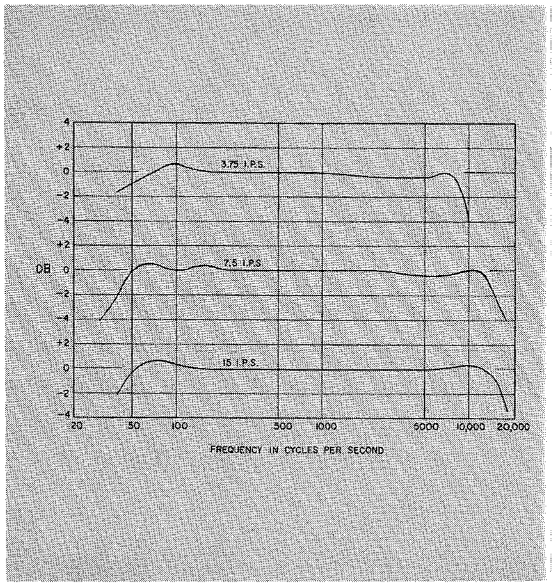


Fig. 7—Frequency response and S:N ratio of the RT-21A.

Speed, ips	Response, db @ cps	S:N, db
3.75	±2 @ 50- 7500	50 half-trk
7.5	±2 @ 40-10,000	50 half-trk
7.5	±4 @ 30-15,000	55 half-trk
15	±2 @ 50-15,000	60 full-trk

SUMMARY

The new RT-21A recorder is well equipped to provide the recording needed for an increasingly broad field of application. It is a professional instrument. Although primarily intended as a sound recorder, it can be used in machine control applications, analog instrumentation applications, and many other applications where signals in the audio-frequency range need to be recorded.

ACKNOWLEDGMENTS

Acknowledgments are due to those members of the Electronic Recording Products Engineering group who participated in the work described. Particular thanks are due to George Singer, Arnold Jackson, and C. B. Meyer for their early engineering efforts on the project.

ELECTROSTATIC IMAGE AND SIGNAL RECORDING

I. M. KRITTMAN, T. H. MOORE, and DR. E. C. HUTTER, Mgr.

Physical Research
Astro-Electronics Division
DEP, Princeton, New Jersey

Electrostatic recording of optical images in a special TV camera tube has been found to permit storage of high-quality TV pictures for periods of weeks. For readout, the tube generates the same video output signal as conventional camera tubes. The substrate of the combined optical pickup-storage medium may be either a glass faceplate or a length of flexible tape. Extensions of these techniques are being studied for recording both digital and analog signals.

SPECIAL SATELLITE requirements have motivated a continuing investigation of information storage in the form of electrostatic charge distributions. The special requirements include ability of the vehicle to accept visual input data from an optical system, to store this information on a reusable medium, and to transmit these data on command as video signals to the ground. The entire process must not seriously degrade the original optical input. The electrostatic image storage system (the product of five years of research and development) is particularly adapted to meet these requirements and to operate in special satellite environments that include high vacuums and Van Allen radiation.

The original work leading directly to the electrostatic image storage system was performed by members of the Technical Staff of the RCA Laboratories. The effort has since been continued by the same personnel in successive RCA departments and divisions concerned with satellite systems. Current work in this area is centered in the Astro-Electronics Division at Princeton. It includes company and contract-sponsored programs for research and development of basic principles, for development of specific cameras, and for adapting some of the techniques developed for the image storage system to the requirements of computer memories and other signal storage devices.

In the first section of this article, the general characteristics and operating principles of the image storage system are described and some results of experimental work performed at AED are presented. In the second section, some results of recent theoretical and experimental work on electrostatic storage of digital and analog signals are discussed.

ELECTROSTATIC IMAGE STORAGE

In addition to those characteristics desired in most conventional camera sys-

DR. EDWIN C. HUTTER received his degrees in Physics from the University of Virginia: the B.S. (Cum Laude) in 1939, the M.A. in 1941, and the Ph.D. in 1943. From 1943 to 1947, he was a research physicist at the RCA Laboratories, where he worked on early electronic fire-control equipment, and also analog computers for guided-missile simulation. In 1947, he became a research associate at the Institute of Textile Technology, at Charlottesville, Virginia; and in 1949, he joined the Acetate Research Laboratories of the E. I. duPont de Nemours Company. He returned to the RCA Laboratories in 1951 to work on Project Typhoon (for which he received an *RCA Achievement Award*), and other general flight-simulation projects. Dr. Hutter was placed in charge of the studies relating to environmental problems and power supply for satellite study project, and continued in this capacity for the succeeding Project Janus, the forerunner of the TIROS project. Upon the formation of the Astro-Electronics Division in 1958, he was appointed Manager of Physical Research. Among other projects, his group is developing electrostatic tape for satellite TV camera applications. Dr. Hutter is a member of the Institute of Radio Engineers, the American Physical Society, and Sigma Xi.

IRWIN M. KRITTMAN received his B.E.E. degree from the City College of New York in June 1957. He completed his course requirements for the M.S. degree in Electrical Engineering at the University of Pennsylvania during 1957-1959 under the RCA Graduate Study Program. From June 1955 to September 1955, Mr. Krittman was at the Naval Research Laboratory. From June 1956 to September 1956 he was with the Bell Aircraft Corporation, where he performed analytical studies of magnetic shielding and voltage control problems. Mr. Krittman joined the Special Systems and Development Department of RCA in 1957, and transferred to the Astro-Electronics Division upon its formation in 1958. As part of his assignment on Project ACSI-MATIC he completed a study of mathematical models and the uses of statistical approach. Since 1958, he has been with the Physical Research Group and associated with various electrostatic image and signal recording projects performing analytical studies of satellite system components and experiments in television techniques and vacuum technology. Mr. Krittman is a member of Tau Beta Pi, Eta Kappa Nu, the ARS, and the IRE: PG Electron Devices. He is a professional Engineer-in-Training in the State of New York.

THOMAS H. MOORE received the B.S.E.E. degree from the Virginia Polytechnic Institute in 1952, and has since completed the course requirements for the M.S.E.E. at Rutgers University. In June of 1952, he joined the RCA Laboratories at Princeton, New Jersey where he worked on an electronic facsimile project. Starting in November 1952, Mr. Moore spent two years in the U. S. Army, at the Coles Signal Laboratory, Fort Monmouth, New Jersey. He rejoined the RCA Laboratories in November 1954, and engaged in research and development on a transistorized magnetic core sync generator, and on resonant deflection circuits. Mr. Moore joined the Special Systems and Development Department of RCA in 1957, and in 1958 transferred to the Astro-Electronics Division. Since 1955, he has been working on electrophotographic and electrostatic storage systems for satellite television systems. He is presently in charge of part of the research on electrostatic storage cameras suitable for satellite applications. Mr. Moore is a member of Phi Kappa Phi, Eta Kappa Nu, Pi Delta Epsilon, and Sigma Xi.

tems, such as high resolution, high optical sensitivity, and good grey-scale rendition, a satellite camera should have certain special abilities. Among the necessary features are:

1) Picture storage for periods up to several orbits—a period limited to no more than a few days.
2) A readout process which results in an electrical signal for modulating a TV transmitter.
3) A recording medium easily erased and reused.
4) A recording medium insensitive to Van Allen radiation — especially to any cumulative effect over a long lifetime of a satellite.
5) A high information packing density on the storage medium to reduce size, weight, and power requirements. For these same reasons, any associated apparatus should be as simple as possible.
6) A very long unattended operational life. This requirement works against systems using high-speed moving parts.
7) Operation in vacuum. This requirement prevents use of volatile components, such as chemicals, for development.

Consideration of these requirements shows that combinations of presently available items are inadequate for sophisticated observation satellites. Besides their more obvious disadvantages, combinations such as film-flying spot scanner or vidicon-magnetic tape cause unnecessary information loss because of the number of image processing steps. Consideration of the above requirements leads to the development of the electrostatic image system as most nearly meeting all of them.

Basic Operation

The transducer is composed of electron guns and conventional focussing and deflection coils, with a target consisting of a transparent support, a transparent backing electrode, a high quantum efficiency photoconductor, and a layer of insulator (Fig. 1). The transparent support presently used is Du Pont Cronar movie film base. (*Cronar* is the registered trade mark for Du Pont's polyester film base.) The transparent backing electrode is a thin evaporated film of gold, chromium, or other suitable metal, and the photoconductor used for sensitivity in the visible red is antimony trisulfide, the same chemical compound that is used in commercial vidicons. The insulator layer used at present is pure polystyrene deposited from a glow discharge in styrene vapor. On each side of the sensitive area of the tape is a metal strip which serves as an electrical contact to the backing electrode. It is possible for this metal strip also to serve as a spacer to prevent physical contact between adjacent layers of tape on the storage reel.

A schematic drawing of a phototape camera and a lumped-constant electrical equivalent circuit is shown in Fig. 2. The electron beam energy (typically 300 volts) is such that the ratio of secondary electrons emitted from the target to incident primaries is greater than unity. Under this condition the electron beams function as a switch and are so shown. In step 1, a potential difference V is applied across the series RC circuit formed by the photoconductor and insulator layers of the phototape. This potential is applied through an electron flood beam, and the photoconductor can be in either darkness or uniform light. The contact is maintained for a period of time equal to many time constants of the series RC circuit. At the end of this period, a uniform potential difference equal to the applied voltage V is established across the insulator layer. The electron flood beam is turned off and the applied voltage is reduced to zero. Now all remnants of previous pictures are removed from the insulator, and the tape is ready for optical exposure.

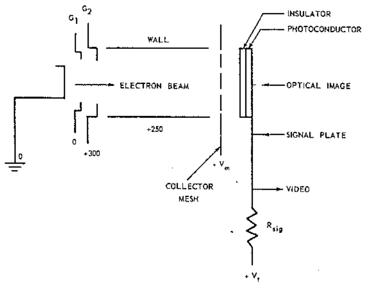


Fig. 2a—Electrostatic storage-tape operation.

In step 2, an optical image is projected onto the photoconductor, and simultaneously the electron flood beam makes contact with the surface of the insulator. In this step the only potential difference around the equivalent circuit is that which has been stored on the insulator layer. This charge on the insulator can now decay towards zero. In areas of the tape where the optical image is brightest the photoconductor resistance will be lowest and the potential decay will be most rapid. The potential decay for a light and a dark area of the optical image is shown in Fig. 3. At a time (t_e in Fig. 3) corresponding to the optical exposure, the electron flood beam is turned off and the discharging process stops. An electrostatic charge image corresponding to the optical image is now fixed on the insulator layer. The tape can now be rolled up and stored for the required length of time.

To convert the stored electrostatic charge pattern into a video signal for transmission to the ground, the tape is moved in front of an electron gun giving a finely focussed beam. The original potential difference V is established around the circuit and the tape is scanned by the focussed beam. Each individual elemental area of the tape, when contacted by the beam, charges from its stored potential back to the original potential V. The charge required to do this

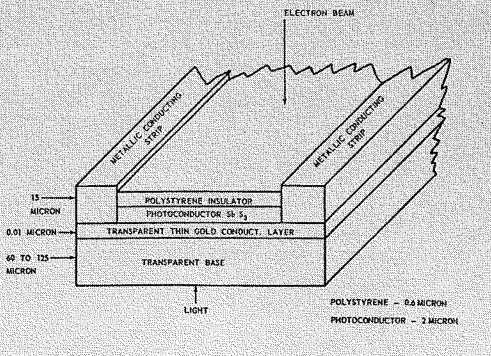


Fig. 1—Electrostatic storage-tape construction.

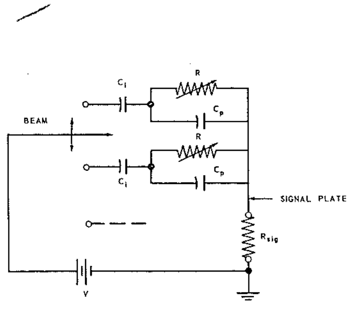


Fig. 2b—Equivalent circuit.

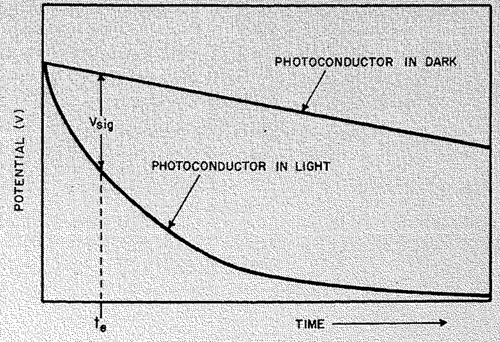


Fig. 3—Insulator potential decay.

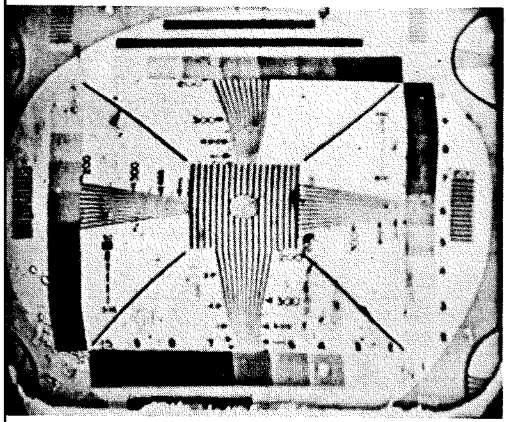


Fig. 4—Kinescope display of picture stored on rolled-up tape for 45 hours.

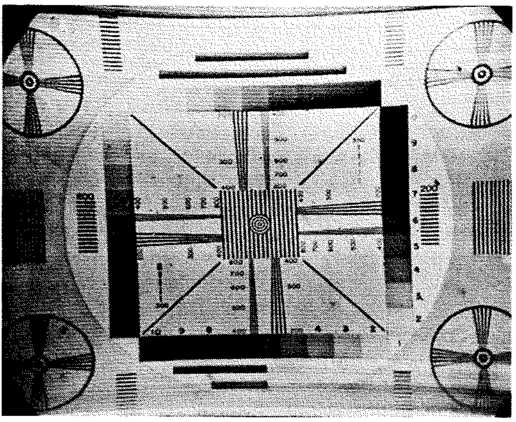


Fig. 5—Kinescope display of picture stored on storage vidicons for 4 days.

is measured by a signal resistor, R_{sig}; the voltage developed across this resistor constitutes the video signal, which can then be processed with conventional TV equipment.

The description of operation given above is for the simplest operating cycle; other cycles are also used. Also, either the target current (as described above) or the return beam (as in an image orthicon) can be used to form the video signal.

Design Considerations

The signal produced by the optical exposure is epN coulombs, where: e is electronic charge, N is the number of photons absorbed, and p is the number of electrons (or holes) extracted from the photoconductor per incident photon.

During writing, the photoconductor and insulator capacitances are in parallel, and the signal charge stored on the insulator is:

$$Q_s = \frac{epNC_i}{C_i + C_p}$$

During reading the capacitances are in series, and the signal charge through the signal resistor is:

$$Q_o = \frac{Q_s C_p}{C_i + C_p} = \frac{epNC_iC_p}{(C_i + C_p)^2}$$

For a given p and N, the maximum value of Q_o is obtained when $C_i = C_p$.

The effectiveness of Q_s in modulating the reading electron beam is determined by the voltage which it produces on the insulating layer. This voltage is Q_s/C_i. The requirements for high sensitivity are seen to be: p large, $C_i = C_p$, and C_i small. From this, it follows that the ratio p/C_p is a measure of the quality of a photoconductor for application to electrostatic tape. Rose and Lampert[1] show that for simple photoconductors:

$$p = \frac{t_o}{RC_p}$$

Where: t_o = risetime of the photocurrent in R, R = photoconductor resistance, and C_p = photoconductor capacitance. The photocurrent risetime must be shorter, and the time constant longer, than the optical exposure. This limits the quantum efficiency, p, to values near unity. Typical measured values of p are 0.03 to 0.3.

The storage time for an electrostatic charge image is determined by the ohmic relaxation time of the insulator layer. The insulator layer must be about 0.6 micron thick to obtain a capacity match with the photoconductor, and it must withstand over 20 volts to provide an adequate electric field for the photoconductor. The field across the insulator is then about 300,000 volts/cm. The storage time required is at least 90 minutes, and thus, the ohmic relaxation time of the insulator at this field must be long compared with 90 minutes. The requirements for this insulator are, therefore, quite severe.

A photoconductor has been chosen as the light sensitive element for several reasons: 1) A photoconductor permits forming the stored image directly from the optical input and directly on the storage medium; this gives a system with a maximum of simplicity and a minimum of limiting apertures. 2) The quantum efficiency of a photoconductor in the visible red is quite high; use of a photoconductor, therefore, results in high sensitivity. 3) The tape transport must have precision mechanical parts, which cannot tolerate the heat treatment normally given vacuum tubes; the residual atmosphere in a tape camera will, therefore, not be as pure as that in normal vacuum tubes. The photoconductor, being relatively inert chemically, is not affected by the gases in the residual atmosphere.

The resolution of the phototape itself can be influenced by three factors: light-scattering in the photoconductor, photoelectron diffusion in the photoconductor, and fringing of the electrostatic field across the insulator. Since the photoconductor presently used is glassy, the light scattering is negligible. A mathematical analysis has been made of the effect of photoelectron diffusion and field fringing on resolution. It indicates that the photoelectron diffusion is negligible, and that the effect of fringing is such that the minimum resolvable dimension will be approximately equal to the thickness

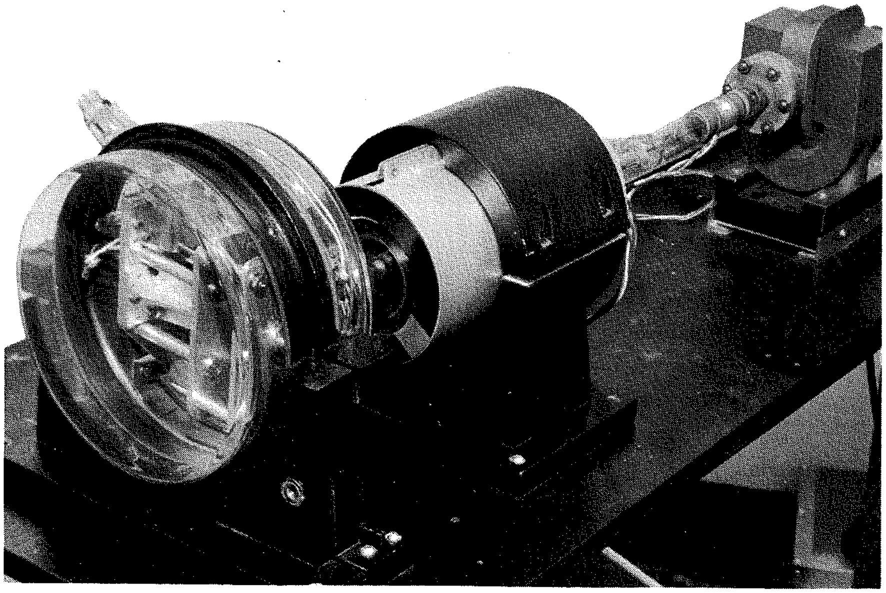


Fig. 6—Experimental sealed phototape camera.

of the insulator. For normal tape this is 0.6 micron, giving a limiting tape resolution of 15,000 TV lines/cm. The calculated N_c of the tape is 3,300 TV lines/cm.

The fact that the inherent tape resolution is so high does not mean that such resolution can be obtained from a tape camera at present. The difficulty is in obtaining a suitable electron gun structure to read this resolution from the tape.

From the above discussion and the description of the phototape operation, it is evident that with the exception of the optical system and transmitter which are common to any system, the resolution of an electrostatic tape camera is essentially determined by only one limiting aperture—the reading electron beam.

The phototape is not optically sensitive except while being contacted by an electron beam, and it is made of materials which are relatively insensitive to radiation. These facts, plus some preliminary radiation tests, indicate that a camera would not be seriously affected by Van Allen radiation.

The tape transport motors and ball bearings must operate in a high vacuum. They must not outgas material which will deposit on or react chemically with internal camera components. Fortunately, because of the high information density of the tape, tape transport speeds are low. There are several types of ball bearings which are suitable for use in vacuum. These include x-ray tube bearings, high temperature bearings, and Teflon-retainer bearings. Motors of the type with solid armatures (and most synchronous motors can be made this way) are relatively easily adapted to use in vacuum. The winding is either potted in a non-volatile material or hermetically sealed. The solid rotor requires no special attention.

Experimental Work

A number of experimental devices employing phototape or phototape targets have been made. These include: fixed phototape targets in sealed 7038 vidicon envelopes, fixed phototape targets in sealed 5820 image orthicon envelopes, a demountable vacuum system with tape transport, and a completely sealed phototape camera.

Pictures have been stored without visible deterioration for various periods up to 2 days on rolled-up tape in the demountable system, up to 2 weeks on rolled-up tape in the sealed phototape camera, and up to 13 weeks in storage vidicons. Sensitivity measurements of storage vidicons show an average peak highlight exposure requirement of 0.01 foot-candle-seconds for a peak signal-to-rms-noise ratio of 15 db.

The resolution obtained in all types of experimental camera devices is approximately 600 TV lines/cm, determined by the ability to control the redistribution of secondary electrons during the reading process. The grey-scale rendition is the same as that obtained from a commercial vidicon, which is as would be expected, considering the similarity. No special problems have been encountered regarding background shading. Photographs of the kinescope display of pictures stored on rolled-up tape and on storage vidicons are shown in Figs. 4 and 5.

The experimental sealed phototape camera is shown in Fig. 6. It consists of a short length of phototape and a bidirectional stepping motor with gear train to move the tape between two reels. Reading and writing are done with an image orthicon electron gun. The camera is evacuated by a Varian Vac Ion Pump.

ELECTROSTATIC SIGNAL RECORDING

Extensions of the principles and techniques underlying the electrostatic tape camera are being investigated for application to electrical signal storage. Although electrostatic storage of analog and digital data has been examined for nearly 30 years, recent improvements in electron guns and materials techniques have revealed new possibilities in this area. The results of the effort to date indicate that improved signal storage (including increased bandwidth and $S{:}N$) can be performed by electrostatic tape recorders.

Analog Signal Recorder

In the analog recorder, the storage medium will consist of a continuous layer of insulator (probably polystyrene) deposited on a conducting substrate. The photoconductor layer required for optical sensing by the electrostatic tape camera is omitted in the signal recorder. The electrical data to be stored are applied as input signals to the control grid (or cathode) of an electron gun; writing is usually effected by a high-velocity beam. Reading can be performed via the same electron gun; high-velocity return-beam readout is usually employed.

With respect to recording characteristics, it is important to consider the relationship between data packing density and $S{:}N$ resulting from high-velocity return beam readout of electrostatic tape. For the analog signal recorder, the output $S{:}N$ is given, approximately, by:

$$S{:}N_0 = \sqrt{\left[\frac{1}{1 + \frac{\sigma}{(\sigma-1)^2} + \frac{2fC}{kR^2}\,\frac{\sigma+1}{(\sigma-1)^2}\left(\frac{2fC}{kR^2}\,\frac{I_0}{I_B} + \sigma - 1\right)}\right]\frac{I_B}{2ef}}$$

Fig. 7—Reading bandwidth vs. packing density, analog electrostatic recorder.

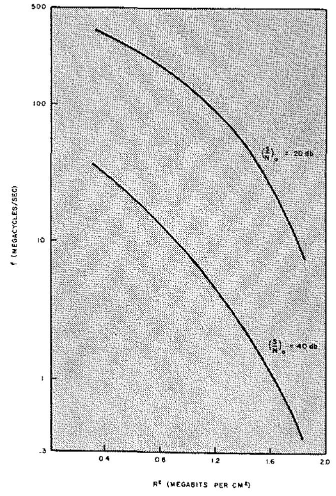


Fig. 8—Sample section of digital electrostatic storage target.

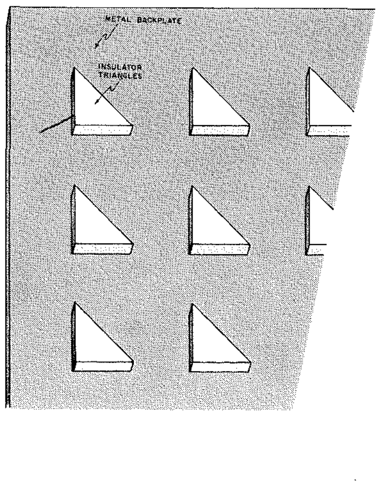
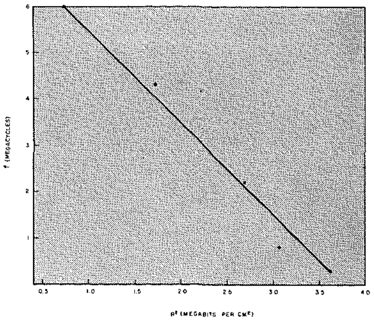


Fig. 9—Writing bandwidth vs. packing density, digital electrostatic recorder.



Where $S{:}N_O =$ output peak-signal-to-rms-noise (current) ratio,

$C =$ target capacitance, farads/cm^2,

$e =$ electronic charge, coulombs/electron,

$f =$ bandwith, assuming the same value for write-in and readout, cps,

$I_B =$ primary beam current, assuming the same value for writing and reading, amperes,

$I_O =$ secondary collector current returning from a black-level element on the target, amperes,

$k =$ slope of the linear portion of the secondary-electron collector characteristic, amperes/volt,

$R^2 =$ data packing density, bits/cm^2, and

$\sigma =$ secondary-emission ratio of the insulator over the range of primary-electron energies from black-to-white-level target voltage.

Values of k, I_O and σ have been determined from actual secondary-electron collector characteristics (for polystyrene under 300-volt average primary-electron bombardment). Substituting these values into the $S{:}N_o$ expression yields:

$$S{:}N_O = \sqrt{\left[\frac{1}{7 + \frac{100fC}{I_B R^2}\left(\frac{20fC}{I_B R^2} + 1\right)}\right]\frac{I_B}{2ef}}$$

For the analog signal recorder, $S{:}N_o$ increases with primary beam current and decreases with target capacity and bandwidth. An increase in beam resolution (or data packing density) necessitates a decrease in beam current and, therefore, in $S{:}N_o$.

The effects of these parameters on recorder performance are demonstrated in Fig. 7. Bandwith is plotted against packing density for two recorder $S{:}N_O$ values. Values for the data packing densities (corresponding to given primary beam currents) are based on the results of monoscope experiments performed by Dr. S. Gray using standard image-orthicon guns. A 10-micron layer of polystyrene (producing a target capacitance of 0.2 nanofarad/cm^2) is assigned to the recorder tape; this figure is based on estimates of present capabilities.

Digital Signal Recorder

In the digital recorder the storage target consists of a metal backplate (deposited on a suitable substrate) covered by a mosaic of triangles of insulator material (tentatively polystyrene). Input signals for writing information onto the target are applied to the cathode of an electron gun as either positive or negative pulses. These pulses cause the beam electrons to approach the target with either low or high velocity. The electrons drive the insulator triangles to one of two equilibrium potentials: either the cathode reference or the secondary collector voltage. The control grid is coupled to the cathode of the write-read gun to maintain constant beam current.

The electron gun, which operates the device in both the high-and low velocity modes for reading as well as for writing, has a sharply focussed beam which can be positioned to a point on the target by applying appropriate currents to a deflection yoke. Data readout signals are obtained from an electron multiplier. Charges lost by individual storage bits are replenished by the reading process so that the elements are maintained indefinitely at the potentials established in writing.

The triangular bits depicted in Fig. 8 serve as the basic elements of a beam position control system. An electron beam scanning the target along a row of storage elements lands alternately on a triangular bit and the conductive backplate, generating a series of current pulses at the backplate. If the beam tracks horizontally without changing speed or direction, the backplate current pulses will be of standard frequency and width. During a beam scanning operation each series of backplate current pulses is compared with the standard train (e.g., via a synchronous detector). The resulting error signals are applied to the inputs of a deflection system to correct the tracking deviations. In this manner the beam can be made to track or follow any line (or column) of storage bits in the target array during any beam scanning operation. This ability to generate a signal for closed-loop control of the write-read gun beam position represents the most important feature of this storage device.

For the digital recorder the main concern is with the writing bandwidth. The primary beam current required for writing is given, approximately, by:

$$I_B = \frac{1.77K}{4(\sigma - 1)} \frac{f}{R^2} \times 10^{-8}$$

Where: $I_B =$ primary beam current required for writing, amperes,

$f =$ "writing" bandwidth, cps,

$K =$ dielectric constant of the insulator,

$R^2 =$ data packing density, bits/cm^2, and

$\sigma =$ average secondary-emission ratio of the insulator as the storage-surface potential rises from its *0* bit to *1* bit value.

Substituting the experimentally determined values of K and σ (for polystyrene) into the above expression yields:

$$I_B = \frac{3f}{R^2} \times 10^{-8}$$

Because of the dependence of beam resolution upon beam current, the bandwidth available for writing decreases when the data packing density is increased. In Fig. 9, the writing bandwidth is plotted against packing density for a digital recorder employing a standard image-orthicon gun.

Future Effort

The feasibility of electrostatic signal recording has been demonstrated in single-target vacuum tubes. Television signals have been successfully stored on continuous insulator targets; readout has been destructive, but there are indications that essentially nondestructive readout can be obtained. Satisfactory binary storage has been realized by prototype targets employing tiny squares of polystyrene. Measurements indicate that the $S{:}N$ associated with the backplate current is quite sufficient for a beam position control system.

A logical extension of the effort to date is the development of analog and digital tape recorders. In addition to advanced research on single-target devices, the deposition of extremely thick layers of insulator on tape substrates, the fabrication of storage targets with triangle-arrays, and the synthesis of a beam position control system stand out as major program objectives.

ACKNOWLEDGEMENTS

The results of the combined efforts of many people have been reported above. In addition to expressing their appreciation for the assistance of other members of the Physical Research Group of AED, the authors wish to acknowledge the analog storage work of Dr. S. Ochs of RCA Laboratories.

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1. A. Rose and M. A. Lampert, "Photoconductor Performance, Space-Charge Currents, and the Steady-State Fermi Level," *Phys. Review, 113*, 5; March 1, 1959, Pp. 1227-1235.

ADVANCED RECORDING TECHNIQUES

by **W. R. ISOM, Mgr.**
Electro-Mechanics Group
Applied Research, DEP, Camden, N. J.

Data recording is memory, and memory is basic to intelligence. This spells out the dependence of computers on recording, and its vital role in radar and other information processing based on comparison, sorting, correlation, and integration. Improvement of sophisticated data-processing systems relies heavily on the continuous interplay between techniques and applications. This article is a survey of techniques, since they must, of necessity, come first.

THE HISTORY of the recording art has always involved relating new techniques of the art to the requirements of a system. Recording was a self-contained art until the birth of the electronic industry. The old Victor talking machine, the *Victrola*, was a mechanical-acoustical instrument complete within itself.

The radio fulfilled this purpose better, and the recording art was momentarily eclipsed; but recording was born anew to make radio more versatile and to make the movies more real. Recording, in the meantime, had acquired new technical allies. It was no longer mechanical-acoustical — the electron tube allied recording with the electronics industry.

The dynamic speaker and the electric motor certainly combined to make recording partially electromechanical in character. The application of the galvanometer and the Kerr cell to recording on film introduced optics as another full business partner before the decade of the thirties was well under way. Then, television came with its demands on the recording art, and subsequently kinescope recording established itself.

ADVENT OF MAGNETIC RECORDING

World War II brought magnetic recording, which is still being assimilated hungrily by the electronic industry. Yet, even before magnetic recording was firmly established, new developments in Electrofax and plastic recording media had begun, representing another advance in the art.

Throughout this evolution, major work on recording has been carried on by current and predecessor research and development groups at the RCA Laboratories, DEP Applied Research, Industrial Electronic Products, RCA Victor Home Instruments, RCA Victor Record Division, and in the product divisions of DEP. In DEP, the primary product responsibility for magnetic recording rests with the Surface Communications Division under the managership of A. H. Kettler, with H. R. Warren heading development and design engineering.

TECHNIQUES AND DEVICES IN DEP

The following paragraphs and the illustrations on the next two pages will review magnetic-recording techniques of concern to DEP by describing key techniques and mechanisms with reference to the application of each in a system.

Needle Capstan

In applications where space, weight, and power are important and high performance necessary, the needle capstan must be considered. The smallness of the capstan, less than 5/64 inch in diameter, makes speed-reduction gears and puck drives unnecessary. The elimination of parts reduces friction to the extent that a 4-watt motor directly drives 2-inch tape in an application that is functionally similar to the commercial video recorder. Fig. 1 compares the diameter of the capstan with the space for the 2-inch-wide tape.

Air-Bearing Head-Wheel

In recording at high frequencies with scanning wheel speeds up to 25,000 rpm, the ball bearings for the motor shaft limit both the performance and reliability. Air-lubricated bearings solve this problem. Fig. 2 shows a head-wheel assembly in which the ball bearings of the motor have been replaced by sleeve bearings perfectly lubricated by air forced through an annal ring of orifices (lots of oil-holes) arrayed around the bearing at the mid-point of its length.

Loop Machines

Repetitive short bursts of information can best be recorded on tape loops for comparative real time analysis. Air-lubricated tape paths impose no limit on tape speeds under 5,000 ips (300 mph) for loops as long as 200 feet. Fixed heads and longitudinal tracks can be used for video frequencies. In addition, the loop machine (such as the one shown in Fig. 3) has flexibility for frequency conversion, long dynamic delay-lines electronically variable by variable-speed drives, multiplexing, and storage for display monitors. Loop life of several million passes are obtained with no degradation of signal-to-noise or appearance of drop-outs.

Helical-Scan Recorder

The helical-scan approach to video recording provides for as many as six video channels. Radar recording and other classified projects need this continuous recording with the several channels made time-coincident by being recorded simultaneously on one piece of tape. Fig. 4 shows how 2-inch-wide tape is formed in a helix by passing over an air-lubricated mandrel with the oxide facing in. This mandrel is divided longitudinally. An outboard support maintains alignment between the two parts of the mandrel. The longitudinal division in the mandrel allows the tape to be scanned on the inside by the head or heads of a scanning wheel. This forms a long diagonal, 28 inches for an 8-inch-diameter mandrel. As shown by the sketch, this technique increases the packing density by as much as 38 percent over transverse scanning — another important feature.

(Text continues on P. 30)

W. R. ISOM received his BS from Butler University in 1931, and taught there from 1937 to 1944, when he joined RCA at Indianapolis. He developed the first commercially available TV film projector and many special mechanisms for kinescope recording equipment for advancing film during the vertical blanking time of a TV system, and for sound-recording equipment for both films and magnetic tape. His most recent work has been the development of precise, high-velocity, large-capacity magnetic-recording systems using tape, drums and disks. He has pioneered the use of air bearings, air suspensions, and air-floated heads for video recording, tape and drum memories, and military tape and drum systems for broadband recording and radar data processing. He was instrumental in expanding the advanced environmental-test facilities of RCA. His group also has been responsible for heat-transfer and temperature-control developments in electronic equipment, and advanced mechanical devices, including stabilized platforms and gyroscopes. Mr. Isom is a fellow of SMPTE and a Senior Member of the IRE.

ISOM
Advanced Recording Techniques
Cont'd

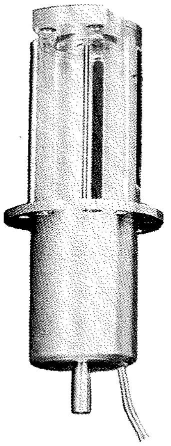


Fig. 1 — Needle capstan eliminates speed - reduction gears and puck drive.

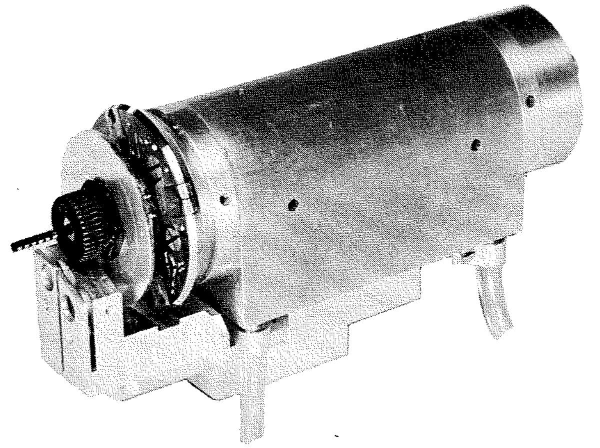


Fig. 2—Air-bearing head-wheel assembly.

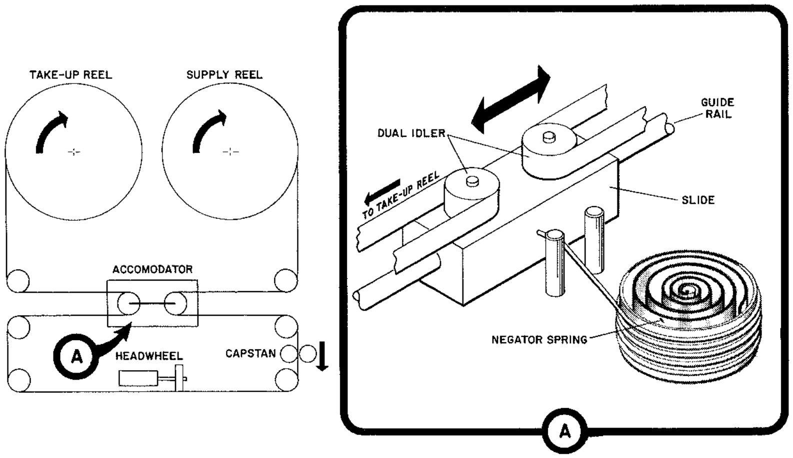


Fig. 5—Accommodator permits critical frequency control during short start-stop cycles.

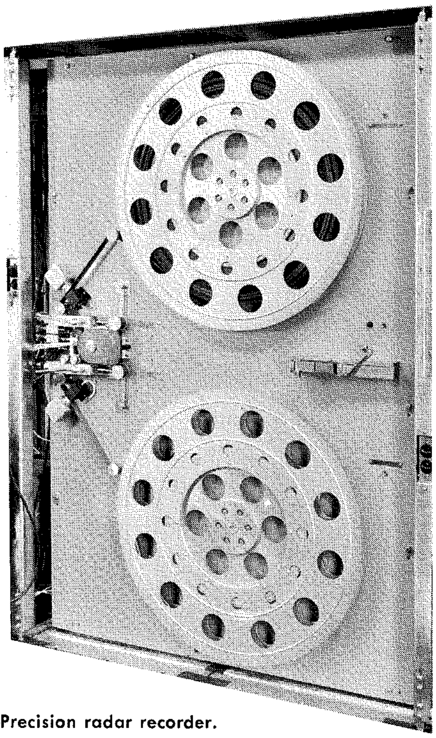


Fig. 6—Precision radar recorder.

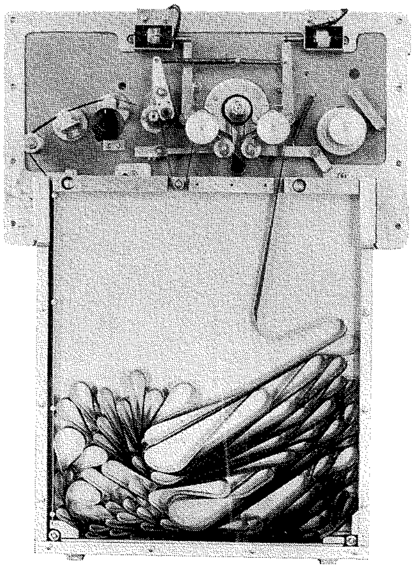


Fig. 9—Medium-range missile launch detector.

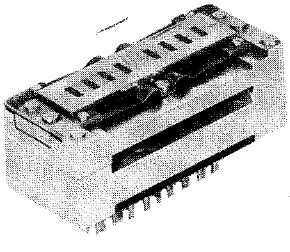


Fig. 10—Dynamically air-floated magnetic heads.

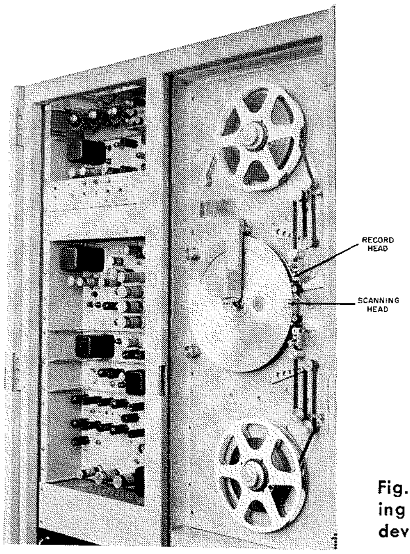


Fig. 11—Traveling raster display device.

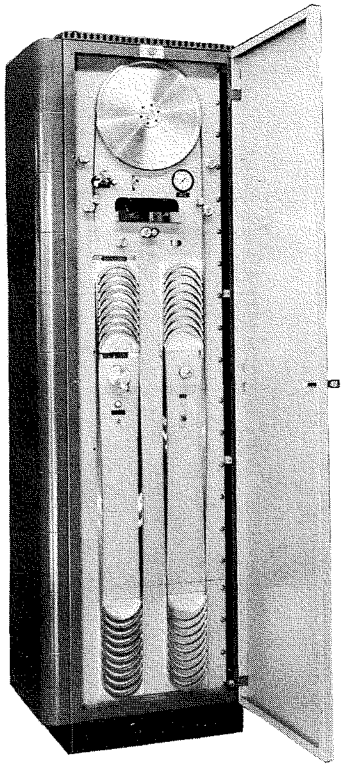


Fig. 3—Magnetic-tape loop machine; crescent-shaped guides are air-lubricated.

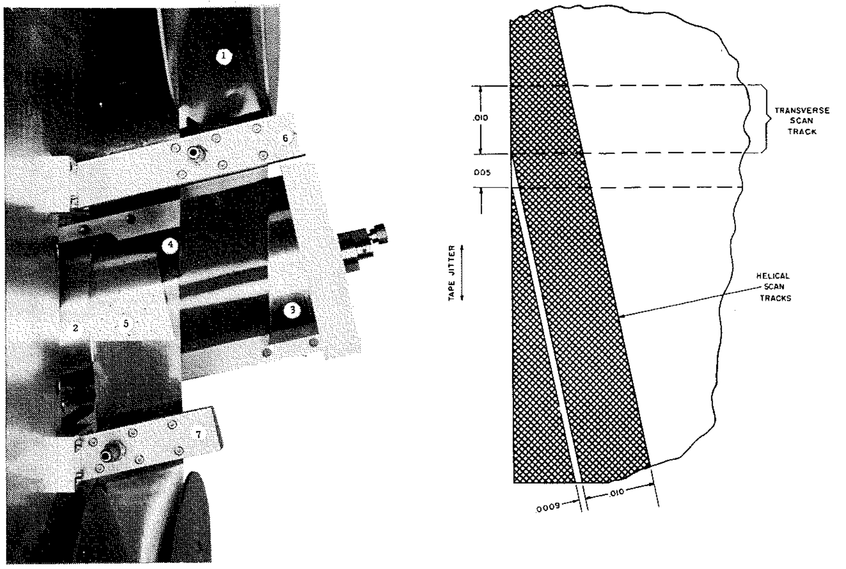


Fig. 4—Helical tape scanner. Photo: 1) tape, 2) and 3) two-piece fixed mandrel, 4) head-wheel, 5) air ports, oxide on tape removed, 6) and 7) air guides. Sketch compares packing density of helical scan with transverse.

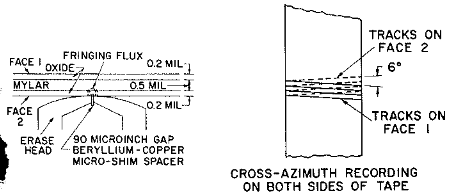


Fig. 7—Techniques making possible the use of thin magnetic tape coated on both surfaces; left: tape cross-section, right: cross-azimuth pattern.

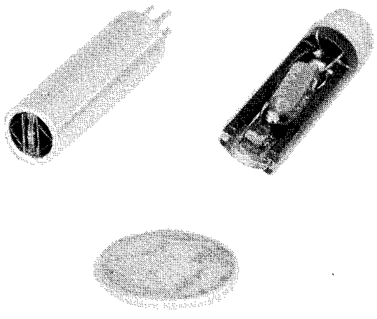


Fig. 8—Pulse record head.

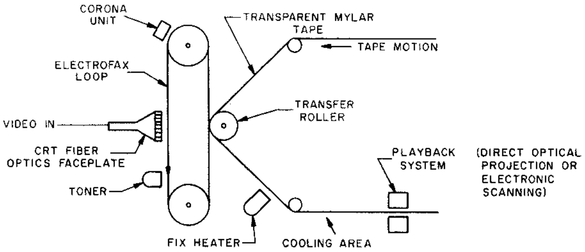


Fig. 13—Read-out of Electrofax recording.

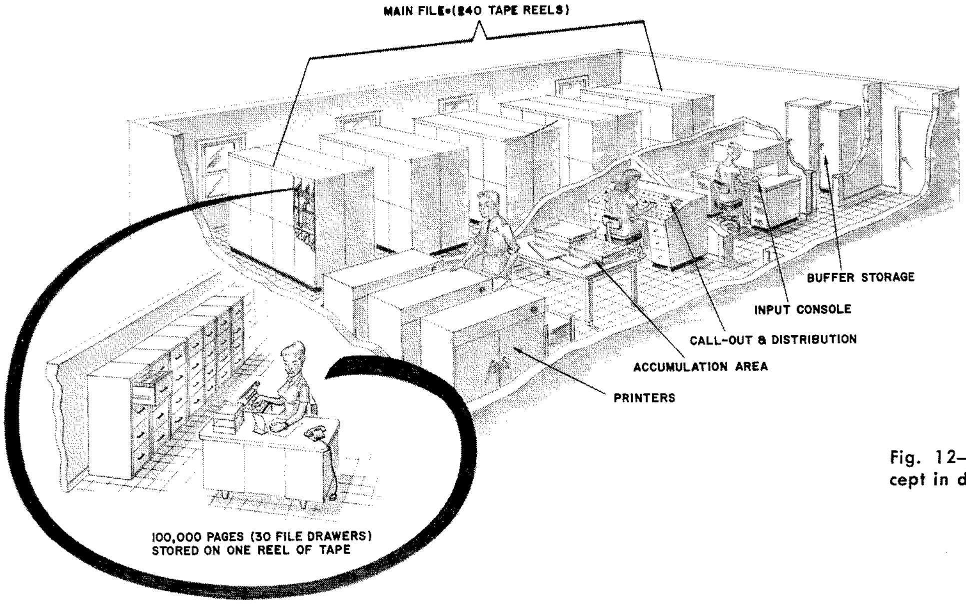


Fig. 12—Video file, a new concept in document storage.

Start Accommodator

Large recording or storage capacity in a tape machine results in large reels with so much inertia that starting or stopping in a fraction of a second is impossible without an accommodator. Accommodators take many forms. The one shown in Fig. 5 provides for uniform tape tension on both the supply-reel side and the take-up side of the capstan. Thus, frequency is accurately controlled during the start and stop cycles. Essentially, the accommodator uses a loop of tape on both sides of the capstan, the tensions of which are maintained equal by the dual idler on a carriage centered by a linear negator spring. This structure is simple, reliable, and fast-acting to permit 1/10-second starting time for video recording.

Precision Recording

The most precise multichannel recorder yet built has fifteen 3-Mc channels stabilized against time within 0.5 μsec (Fig. 6). To achieve this performance, the tape was driven at 1,000 ips (approximately 60 mph) with a direct-drive air-turbine capstan with air-lubricated bearings. Also, the irregularity of the conventional pressure rollers was avoided by using air pressure directly to lock the tape to the capstan. The ultimate in performance was obtained by this means for a very critical radar-analysis project.

Recording on Both Sides of Tape

To increase the density of information storage so that air-borne magnetic recording is practical, tape is coated with magnetic oxide on both surfaces. To further increase the density, the thickness of the tape itself is reduced by one-half. Three techniques permit the use of this high density tape: 1) frequency-modulation recording in which the longest wavelength of the carrier is a fraction of the thickness of the tape (0.5 mil), preventing print-through; 2) orienting the head on each side of the tape so that its azimuth is crossed with respect to the head on the other side of the tape by some 6 degrees, preventing contact-printing; and 3) using narrow-gap erase heads so that the signal on one side can be removed without affecting the signal on the other side. The tape and the erase technique are shown in one sketch of Fig. 7; the FM carrier penetration (the cross-azimuth arrangement of magnetic tracks), in the other.

Pulse-Recording Head

A recording head for pulse work contains read-write circuitry integral to the assembly. This head eliminates the high-current record and playback amplifiers that are needed for each channel in normal recording installations. Triggered from a lower-power source, it can deliver 400 ma of peak current for 2 μsec at a 250-kc rate. This is accomplished by using a blocking oscillator with an additional winding in the head in the regenerative loop. The read-out circuit is similar. For memory drum use, particularly airborne, this technique reduces circuit complexity, power, and size. The circuitry occupies the space in a drum head normally filled with potting compound (Fig. 8).

Medium-Range Missile-Launch Detector

This equipment completely modernizes and up-dates the old sound-ranging triangularization methodology by using magnetic recording and analog computers. The recordings of the outputs of several transducers in a known geometric array are continually scanned and coincidence of events established by mechanically delaying the recordings each with respect to the others. This is the input to a converter that indicates range and direction. The techniques employed on this project include a tape basket to hold a 4-hour-long loop, a transistor amplifier that rotates with the scanning assembly, and the moveable scanning heads. The recorder is shown in Fig. 9.

Air-Floated Heads

Drums and disks are limited in usefulness by the density with which information can be recorded on them. By floating heads on the boundary layer of air carried by the high-speed oxide surfaces, uniform separations less than 100 microinches can be maintained. Frequencies as high as 8 Mc have been recorded. With the intimate time stability of a high-speed rotating drum or disk, this floating-head technique gives a memory that operates at computer speeds. Fig. 10 shows multichannel, dynamically air-floated magnetic-recording heads.

Traveling-Raster Display Recorder

Slow-speed video information in the form of the output of an air-borne infrared system or a sonar system is recorded longitudinally on the tape, line by line, just before the tape passes around the scanning wheel (Fig. 11). The circumference of the scanning wheel is several hundred times greater than the length of one line of information. Also, the linear speed of the scanning head on the wheel is several hundred times the head-to-tape speed during recording. Hence, the scanning wheel head scans a raster of lines during each revolution and converts the information to video frequency for display on a monitor. The information on the monitor appears to travel in the same manner as it did when viewed originally from the vehicle carrying the sensor. This traveling-raster technique is applicable to projects using frequency-analyzer scanning information spectrums.

Video File

The role of recording for Defense Electronic Products is somewhat shrouded by a cloak of security classification. Therefore, it is difficult to explain a so-called "DEP" recording system. However, the integration of recording techniques into systems can be illustrated by a new development in information storage called *video file.* The system shown in Fig. 12 has both commercial and military application.

In this system, documents are electronically scanned, stored, and indexed on video tape. On call-out, the tape is searched, the document is recorded in electrical form on a buffer store which feeds a viewing monitor or an Electrofax printer. In other words, within a few minutes, an authentic image of the original document may be viewed, or any number can be printed out and delivered automatically. The statistics are astounding. *One reel* of 10,000 feet can store the contents of *25 file drawers or about 100,000 pages.* The direct cost of a page printed out is mainly paper cost. This system is principally a recording system and its impact upon business could exceed that of the computer.

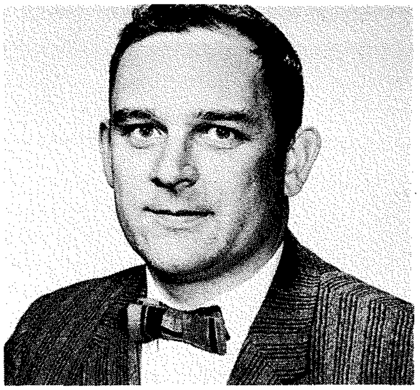
Recording Research

Just as recording has been allied with branches of the electronic industry, new developments are likely to ally it with the plastics and printing business. A new approach to recording uses an Electrofax material for defining an image in latent form as an electrostatic charge pattern. This pattern is toned and transferred by contact to a transport Mylar tape. If a permanent record is desired, the toned image on the Mylar tape is fixed by heating. Read-out is by one of several means, optical or electrical. This recording is done without vacuum, and has the advantage of a visual image. The system is illustrated in Fig. 13.

EPILOGUE

Recording in all of its forms has always been an essential part of progress and civilization. As civilization becomes more intricate through automation and more mechanized by learning and teaching machines and by computers, the more it will be preserved and controlled by the minute transfigurations of the physical properties of endless miles of thin webs of recording media.

For project DAMP, the position of the floating instrumentation laboratory **USAS American Mariner** must be known to a high order of accuracy. To evaluate these requirements, an extensive analysis of the complete DAMP system was conducted under the leadership of the author. Of particular concern were shipboard operation of the radar-gyro combination, data-recording instrumentation, re-entry dynamics, and missile cross-section characteristics. A satellite navigation system was selected, the basic characteristics of which are described herein.



R. LIEBER graduated with a BS in ME from the University of Miami and received his Master of Science degree from Drexel Institute of Technology. At the Army's Frankford Arsenal from 1950 to 1952, Mr. Lieber was responsible for hydraulic circuit design and development. Joining RCA in 1952, Mr. Lieber contributed to design and development of the AN/APN-42 subminiaturized pulse radar altimeter and the "Black Cat" low-altitude penetration system. He then became responsible for the integration of the MIT-SPIRE System with the RCA-developed K-band terrain clearance radar. From 1956 to 1958 Mr. Lieber undertook the functional engineering of inertial navigation systems and self-stabilized missile-seeker systems. Since 1958, Mr. Lieber, as Leader of an Analysis group, is responsible for major portions of the AICBM Program, DAMP, and advanced ground-located tracking and guidance systems and techniques.

SATELLITE NAVIGATION SYSTEM FOR PROJECT DAMP

by **R. LIEBER**
Tracking, Guidance, and Navigation Systems
Missile and Surface Radar Division
DEP, Moorestown, N. J.

THE RCA-EQUIPPED *USAS American Mariner* (see photo, below) is a roving, floating instrumentation laboratory site for Project DAMP (the Down-range Anti-ballistic-missile Measurement Program). Outfitted with precision RCA measurement equipment, the ship acts as the focal point for a data-handling system. The successful transmission of data to closely integrated activities relies on the highly accurate tracking of missiles, position-fixing, and acquisition of data. [Earlier papers in the RCA ENGINEER have described the range and purpose of Project DAMP[1] and the operation of the over-all system equipment, including a complete radar video-tape recorder.[4] As a sequel to these articles, this paper provides the basic theory behind a navigation component of DAMP's complex electronic measuring equipment.]

HIGH ORDER OF ACCURACY REQUIRED

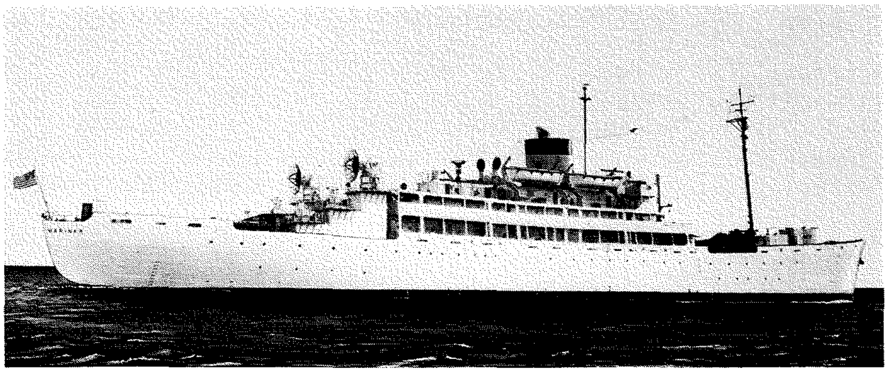
DAMP measurement equipment has been installed by RCA aboard the *USAS American Mariner* for the purpose of deriving information necessary to the defense against ballistic missiles. The information is gathered by tracking missiles fired from Cape Canaveral. Because of the capability of present-day missiles, the ship must operate in areas not covered by precision electronic navigation aids and under weather conditions that often render conventional celestial navigation methods useless. For the shipboard instrumentation system to perform at maximum efficiency in the acquisition and tracking of targets, it is necessary that the position of the ship be known to a high order of accuracy.

A number of different position-fixing systems, applicable to ship precision navigation, were investigated prior to the choice of the satellite navigation system for the *USAS American Mariner*. A short summary of this study is given in Table I.

POSITION FIXING

The classical method of celestial navigation (Fig. 1) requires that two angle measurements, called *star sightings*, be made. The star sights and the times at which they were made are used as entries to a set of star position tables, called *ephemerides*. Using the tables, a position fix is computed. In contrast, the artificial earth satellite system (Fig. 2) requires the reception of a continuous wave transmitted from the satellite with subsequent detection of the doppler shift by the ship. The detected doppler shift is compared with a computed doppler shift, and the difference between them is used to fix position. The doppler information is the analog of the star angle measurements of the classical celestial system.

The RCA-equipped *USAS American Mariner*, the roving instrumentation laboratory for DAMP, the Down-range Anti-ballistic-missile Measurement Program.



THEORY OF OPERATION

Three essential steps in the operation of the satellite navigation system (Fig. 4) are:

1) determination of precise satellite ephemerides and injection of the ephemerides into the satellite memory;
2) transmission of continuous-wave and satellite-position information from the satellite to the ground observer; and
3) reception of data from the satellite and computation of own position by the observer.

Step 3 is of major interest, since it represents the system end item — position fixing.

As was pointed out previously, it is necessary to compare the received doppler shift with a computed doppler shift in order to fix position. Because of the practical considerations of power limitation in the satellite and upper frequency limits of transistors, the system operates at uhf. The effect of the ionosphere in producing random doppler shifts is well known, and a scheme for cancelling this effect has been incorporated in the system.

Doppler shift can be expressed[2] as:

$$\Delta f = \frac{f}{c} \, \frac{d}{dt} \left[\int_{f^{(t)}} n ds \right] \qquad (1)$$

And, approximately, as:

$$\Delta f = \frac{f}{c} \dot{r}(t) + \frac{\alpha(t)}{f} + \frac{B(t)}{f^2} + \ldots \qquad (2)$$

At uhf, terms of higher order than the first in frequency can be neglected. Thus, if a system utilizes two simultaneous frequencies, the $\dot{r}(t)$ at any time can be recovered by the solution of the following simultaneous equations:

$$\begin{aligned} \Delta f_1 &= \frac{f_1}{c} \dot{r} + \frac{\alpha}{f_1} \\ \Delta f_2 &= \frac{f_2}{c} \dot{r} + \frac{\alpha}{f_2} \end{aligned} \qquad (3)$$

With the propagation-corrected $\dot{r}$ available from the above solution, the computation for ship position is performed. The approach taken is to minimize the mean squared difference between a computed range rate and the $\dot{r}$ from equation 3 by suitable choice of ship position. Range rate (Fig. 5) is computed from:

$$R^2 = r_e^2 + r_s^2 - 2\,(x_s x + y_s y + z_s z) \qquad (4)$$

The minimization process[3] leads to:

$$\overline{\left(\frac{\delta \dot{R}}{\delta \lambda}\right)}^2 \Delta\lambda + \overline{\left(\frac{\delta \dot{R}}{\delta \lambda}\,\frac{\delta \dot{R}}{\delta \phi}\right)}^2 \Delta\phi = \overline{(\dot{r} - \dot{R})\,\frac{\delta R}{\delta \lambda}}$$

$$\overline{\left(\frac{\delta \dot{R}}{\delta \lambda}\,\frac{\delta \dot{R}}{\delta \phi}\right)}^2 \Delta\lambda + \overline{\left(\frac{\delta \dot{R}}{\delta \phi}\right)}^2 \Delta\phi = \overline{(\dot{r} - \dot{R})\,\frac{\delta R}{\delta \phi}}$$

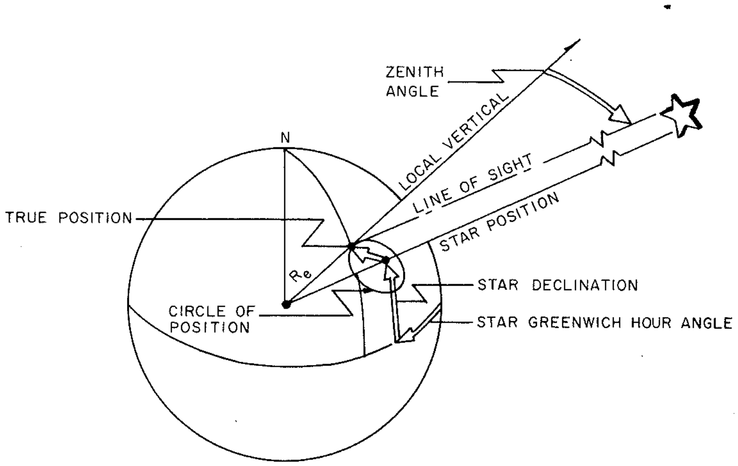


Fig. 1—Simplified celestial position fix. Method: 1) Measure Greenwich mean time and star altitude (90°—zenith angle). 2) Use ephemeris to determine declination and Greenwich hour angle. 3) Determine a circle of position whose center is at star position and radius is equal to zenith angle. 4) Observer's position lies at intersections of two circles of position.

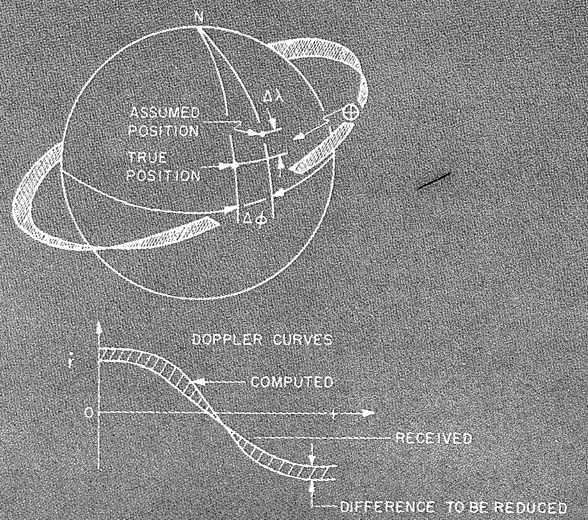


Fig. 2—Artificial satellite navigation. Method: 1) receive cw signal and coded orbital elements. 2) Compute doppler data based on received elements and assumed position. 3) Compare received and computed data, minimizing their difference by adjusting Δφ and Δλ.

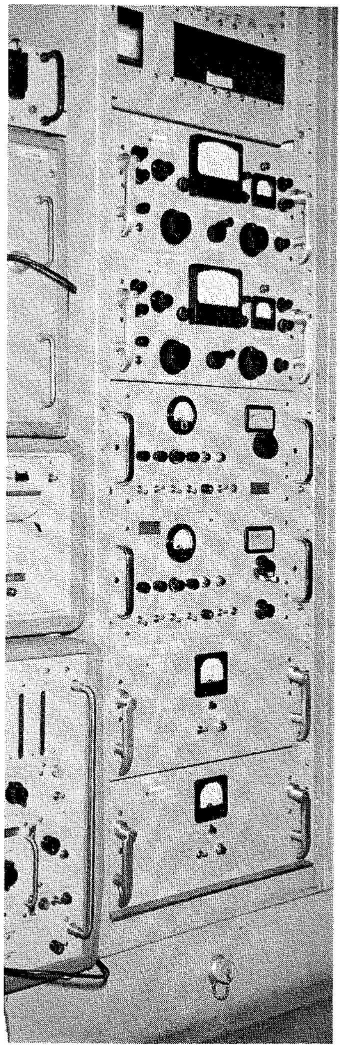


Fig. 3—Equipment, installed on the *USAS American Mariner*, contains rf amplifiers, custom phase-locked tracking filters, and power supplies.

The bar denotes an average over all data. The $\delta R/\delta\lambda$, etc., are derived from the satellite position and estimated ship position through equation 4.

The antennas, receivers and associated electronic gear were installed on the *USAS American Mariner* after first checking out their capabilities in the DAMP Research Center in Moorestown. Also aboard the *American Mariner* is a small general-purpose digital computer (RADAP) used to accurately determine look angles for the radars aboard the *Mariner*, and thus facilitate target acquisition. A portion of this computer is used to mechanize the system equations 3 and 5, above. The output information from the receiving system is fed into this computer on a real-time basis to accurately establish the ship's position for the determination of look angles for acquisition.

The practicability of this precision position-fixing technique has been verified by the data obtained by DAMP from transit satellite tracking and orbital schedules.[2] The continuous-wave-transmitting, artificial earth satellite navigation system used on DAMP offers the following features:

1) all-weather operation, 2) eliminates need for horizon sight or stable local vertical, 3) high accuracy, and 4) simple automatic equipment.

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3. I. Kanter, "A Simple Doppler Navigation Computer," East Coast Navigation Conference, November 1960.
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TABLE I—POSITION-FIXING SYSTEMS

System	*Description*	*Limitations*	*Maintenance & Cost*	*Availability*
Loran C	Pulse Comparison-Phase Comparison system. Requires Loran C receiver.	Transmission does not cover our area. Extension not proposed at this time.	Low maintenance Low Cost	Not available
Radio-Celestial	Celestial angle measurement. Requires antenna gimbals computer.	None	High Cost	1-2 years
Inertial	Gravity tracker system to determine ship position. Requires gimbal system, gyros, accel. computer.	Requires monitoring for best operation over long periods.	Med. maintenance High Cost	1 year
Mils Net	Position computed by sonar. Communication of position via Cape Canaveral.	Range does not cover our area of operation.	None	Now
Doppler-Satellite	Determines position from doppler shift of satellite cw signal. Requires uhf receiver and small computer. High accuracy. Fix frequency is 1 fix/12 hrs./satellite.	Number of position fixes dependent on number of successful launchings.	Low maintenance Low Cost	6 months

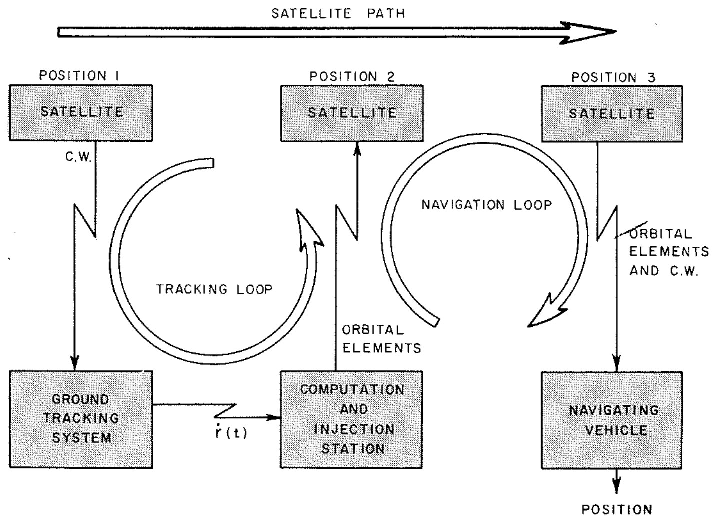


Fig. 4—Operation of Satellite navigation system.

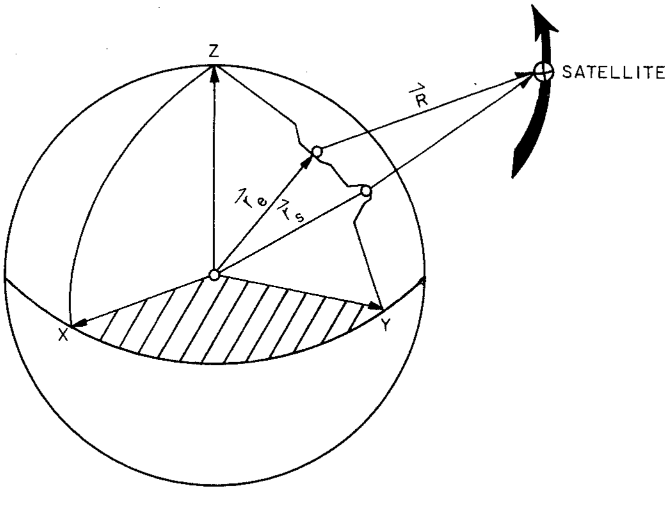


Fig. 5—System geometry for range-rate computations, where: r_e = earth radius; r_s = satellite position; R = line of sight; and X, Y, Z is a fixed-coordinate system.

PLASMA PHYSICS

Part 2—Communications, Propulsion, and Devices

by **DR. M. P. BACHYNSKI, Director**
Microwave Laboratory
Research Laboratories, RCA Victor Co., Ltd., Montreal, Canada

Dr. Bachynski here concludes his survey of Plasma Physics. Part I, "Natural Phenomena and Thermonuclear Fusion," appeared in the previous issue of the RCA ENGINEER, Vol. 6 No. 5, Feb.-Mar. 1961. For the interested reader, a bibliography of important works in this field is included at the end of the article.

Dr. M. P. Bachynski. For his biography, see Part I of this article, Vol. 6 No. 5, p. 30.

COMMUNICATIONS AND PLASMA PHYSICS

The interest in electromagnetic wave interaction with plasmas is many-fold. First, there is the direct application to communication techniques. Second, there is the information which can be derived from a knowledge of such interaction. This is the basis for numerous fundamental studies in physics and diagnostic techniques; in this same category can be included the effects on radar return. In addition, the effect of the plasma environment on the performance of a given system must be considered.

Electromagnetic Wave Interaction with Plasmas

The interaction of an electromagnetic wave with a plasma can be described in terms of a number of bulk parameters of the plasma. These parameters, in turn, depend upon the basic particle interactions. The degree of ionization of the gas or mixture of gases comprising the plasma determines the *electron density*, or number of electrons (the most important constituent) contained within the plasma. The interaction of these electrons with neutral atoms, ions, and with each other determines the *collision frequency* of the plasma constituents — i.e. a measure of the average number of collisions an electron undergoes per unit time. Complicating factors are that 1) the collisions can be elastic or inelastic, 2) the electron can be interacting with several particles simultaneously, and 3) the nature of the interesting forces is different for electron-neutral particle interaction than for electron-ion or electron-electron collisions. The electron density, collision frequency, and external forces determine the conductivity (and in turn the current density) of a plasma. For slightly ionized plasmas, the conductivity is almost exclusively due to the more mobile electrons. However, at high degrees of ionization, the ion conductivity becomes of importance. From a knowledge of the time and spatial variation of these quantities (electron density, collision frequency, conductivity) electromagnetic wave interaction with a plasma can, at least, in principle, be deduced.

A fundamental quantity which enters into a discussion of the properties of a plasma, particularly when electromagnetic wave interaction is concerned, is the plasma frequency. The plasma frequency (ω_p) for electrons in a plasma, regarding the ions as stationary motionless points is defined as:

$$\omega_p = (ne^2/\epsilon_o m)^{1/2}$$

Where: n is the electron number density per unit volume, e is the charge on the electron, m is the mass of the electron, and ϵ_o is the permittivity of free space.

Although the plasma frequency enters into most considerations as a convenient lumped parameter having the dimensions of frequency, it also is an inherent property of a plasma. If, in an infinite plasma, a small number of electrons are displaced from their equilibrium position, a restoring space charge field is created which, if the displacing force is suddenly removed, causes the electrons to oscillate about their equilibrium position at a frequency proportional to the plasma frequency.

The electromagnetic properties of a plasma change markedly depending upon whether the angular frequency of the electromagnetic wave is greater or less than the plasma frequency. For rf frequencies above the plasma frequency, a plasma behaves more or less like a dielectric, the lossiness of which is determined by the collision frequency. At frequencies well below the plasma frequency, the plasma acts like a very good conductor, while at frequencies around the plasma frequency, *cutoff* (very high attenuation and reflection) occurs so that the wave cannot penetrate to any great depth into the plasma.

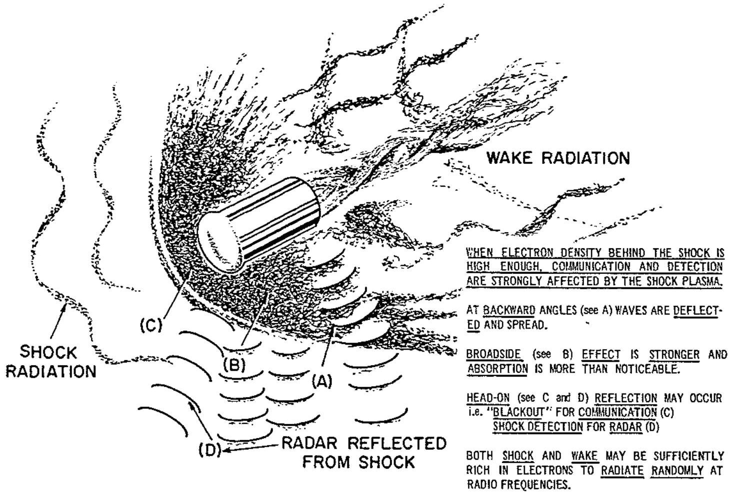
In the presence of a steady magnetic field, the electromagnetic properties of a plasma are drastically modified. In this case, the plasma behaves as a doubly refracting medium and exhibits band-pass characteristics. That is, for certain frequency ranges, depending upon the plasma properties and the strength and direction of the magnetic field relative to the incident wave, the plasma is *transparent* to radio waves, while in other frequency ranges it is *opaque*. This means that for specific conditions, radio energy at frequencies well below the plasma frequency can penetrate through the plasma.

Further electromagnetic-wave–plasma phenomena of considerable interest occur when effects of electron gradients are considered. These nonlinearities in the distribution of the electron density arise as a result of thermal currents in the plasma and give rise to longitudinal waves which travel at very low velocities (some as low as the sound velocity) in the plasma. Thus, the plasma can support a pressure wave in addition to the transverse electromagnetic wave. In most instances, the pressure and electromagnetic waves are coupled and energy can be transferred from one type of wave motion into the other.

Communications and Natural Plasmas

The fact that an ionized region acts as a conductor and hence is a good reflector for incident radio waves of frequency below the plasma frequency has been utilized for communications for some time. Thus, the *ionosphere* is a naturally occurring plasma, and long-distance communication over the earth via reflection from the ionosphere is feasible for frequencies less than a critical frequency (which depends on angle of incidence as well as the electron density). At these frequencies, the radio energy will be almost totally redirected (reflected) down towards the earth again. This is the basis of the so-called sky-wave in modern radio communications.

Extensive exploration of the ionosphere has also been carried out by radio soundings in which a variable-frequency signal is directed at the iono-



WHEN ELECTRON DENSITY BEHIND THE SHOCK IS HIGH ENOUGH, COMMUNICATION AND DETECTION ARE STRONGLY AFFECTED BY THE SHOCK PLASMA.

AT BACKWARD ANGLES (see A) WAVES ARE DEFLECTED AND SPREAD.

BROADSIDE (see B) EFFECT IS STRONGER AND ABSORPTION IS MORE THAN NOTICEABLE.

HEAD-ON (see C and D) REFLECTION MAY OCCUR i.e. "BLACKOUT" FOR COMMUNICATION (C)
SHOCK DETECTION FOR RADAR (D)

BOTH SHOCK AND WAKE MAY BE SUFFICIENTLY RICH IN ELECTRONS TO RADIATE RANDOMLY AT RADIO FREQUENCIES.

Fig. 4—Plasma sheath surrounding a hypersonic space vehicle as it re-enters the atmosphere.

sphere and the reflected wave observed until a frequency is found above which the signal penetrates into the ionosphere and the reflected wave is appreciably reduced. If the electron density of the ionosphere changes, this critical frequency changes. In this manner, it has been possible to determine the stratification of the ionosphere by virtue of the differing electron densities of the various layers. Fortunately, the electron density is greater in the layers at higher altitudes so that frequencies can be found which penetrate the lower layers but are still reflected by the higher regions of the ionosphere.

The newer communication techniques which use meteor trails are based on the same principles. A meteor re-entering the earth's atmosphere creates a column of ionization due to impact on the atmosphere and to ablation of the meteor material. When the electron density is sufficiently large, this cylinder of plasma reflects incident radio energy. The trails are transient phenomena, since because of diffusion, the electron density soon decreases below the critical value for reflection of the electromagnetic energy.

An electromagnetic wave travelling in an ionized region may, under certain circumstances, interact with a second wave in such a way that a modulation imposed on one of the waves becomes transferred to the other. To produce this cross-modulation, or *Luxembourg effect* (so-called because it was first observed from radio station Luxembourg), a nonlinear medium is required; the absorption of energy from radio waves by an ionized region provides the necessary nonlinearity. If, now, another wave (the interacting wave) is absorbed in the same region, the energy from it will increase the velocity of the electrons and hence the frequency of their collisions with the net result that the wanted wave will be more strongly absorbed. Thus, in the presence of the interacting wave, the wanted wave will become weaker. If the amplitude of the interacting wave is varied, the velocity of the electrons will follow and the absorption of the wanted wave will also vary. In this way, the modulation of the interacting wave becomes superimposed on the wanted wave.

Because of the doubly refracting nature of the plasma in a magnetic field, a further effect occurs when radio waves are propagated in a plasma in the direction of the magnetic field lines. This is a rotation of the plane of polarization of the wave, namely *Faraday rotation.* Communication systems whose signals must pass through the ionosphere, for instance, suffer from this effect.

The bandpass behavior of the plasma in the presence of a dc magnetic field, discussed earlier, explains *whistler* propagation. These decreasing-frequency audio whistles observed by radio are the result of low-frequency electromagnetic energy being generated by natural lightning discharges and propagating from one earth hemisphere along the magnetic lines of force of the earth to the conjugate positions of their origin in the opposite hemisphere.

At low radio frequencies, the ions in the plasma profoundly affect the electromagnetic characteristics of the plasma. As a result, the bandpass structure of the plasma is modified, with electromagnetic-wave propagation now being possible at very low frequencies. These low frequency waves are the classic *magnetohydrodynamic,* or Alfven, waves that propagate at a velocity which is often nine orders of magnitude less than the velocity of light. Such magnetohydrodynamic waves have been detected both in the laboratory and during the Argus high-altitude nuclear detonations of 1958.

The Plasma Sheath

A space vehicle moving at hypersonic velocities within a planetary atmosphere will be surrounded by a shock-induced envelope of ionized gas (Fig. 4). This layer of ionized gas, or *plasma sheath,* can have a profound influence on communications and telemetry to and from the vehicle and can also seriously alter the radar reflecting characteristics of the vehicle and, hence, its radar detectability.

The effect of the plasma sheath on communications is to attenuate the signal severely and markedly degrade the antenna performance. At typical re-entry velocities for missiles and space vehicles, the signal attenuation is sufficient to cause blackout, except at extremely high microwave frequencies. For a manned re-entry vehicle which descends slowly in altitude, the plasma sheath ionization can persist over a large part of its flight path. This makes it extremely difficult to guide and control such vehicles from the ground by telemetered signals. The same difficulties apply to information transmitted from space probes and other scientific data measurements. Consequently, it is very important to understand the plasma phenomena created on re-entry in order to select the optimum system requirements.

Of great importance for defense applications is knowledge of the behavior of the radar scattering cross-sections of ballistic missiles at launch and during re-entry caused by the ionized sheaths and trails of the vehicles. In general, the plasma sheath enhances the scattering cross-sections, but under specific conditions, the scattering properties can even be reduced.

Basically, the above phenomena involve the interaction of electromagnetic waves and plasmas. This is, however, only part of the story, since to specify the plasma properties and the plasma geometry at any time a detailed knowledge of aerophysics is required for determining the shock-front configuration and related aerodynamic flow fields and flow rates. These factors, in turn, depend upon the environment in which the body is moving and, hence, upon upper-atmospheric physics; they also depend on the atomic processes of particle interaction in the plasma, and on dissociation, ionization rates and products, etc. This is, indeed, a formidable problem.

Plasma sheath phenomena have been reported associated with orbiting satellites. It is speculated, with some experimental evidence, that because of space charge which may build up on the satellite, a cloud of ions could be projected in front of the satellite. This plasma cloud is thought to be sufficiently dense to reflect high-frequency (megacycle) radio waves at times of intense solar activity. More quantitative measurements are necessary before the existence of this effect can be proven.

Atmospheric Breakdown

Gas *breakdown* or gas *discharge* in a given region occurs when the number of electrons being created by ionization is equal to or exceeds the number of electrons which are lost through diffusion, recombination and attachment. In the breakdown process the residual electrons in the gas gain sufficient energy from the rf electric fields to cause primary ionization by collision with the neutral constituents. Initially, since there are few electrons, the ionizing collisions are infrequent but as the number of electrons created increases an avalanche process is initiated until breakdown occurs. At high pressures, the mean free time between collisions of the electrons is small compared to the rf period, so that the electron does not have time to gain much energy before collision. At low pressures, the time between collisions is long, so that in the interval the electron gains sufficient energy from the rf fields to cause an ionizing collision. At extremely low pressures, there are few particles for the electrons to collide with, so an optimum pressure exists at which a minimum voltage is required for breakdown.

Thus, the electric field strength required to break down a gas at low pressure is, in general, less than that required at atmospheric pressure. As a consequence, even low-power antennas on a high-altitude vehicle may be susceptible to voltage breakdown. The effect on the antenna performance when voltage breakdown occurs is to alter the radiation pattern of the antenna, lower the total power radiated, change the pulse shape of the radiated power and modify the input impedance of the device. When the number density of electrons in the discharge is such that the plasma frequency exceeds the rf frequency, little transmission and considerable mismatch will occur.

Direct application of breakdown theories to antenna–voltage-breakdown characteristics are difficult because of the complex fields existing near the antenna that vary with the antenna configuration. The effect of pulse shape, pulse repetition rate (since electrons may be left in the gas in front of an antenna by the previous pulse), and peak powers under varying conditions before breakdown occurs are yet not fully understood. The environmental conditions of a space vehicle complicate the problem because of the questionable validity of concepts such as diffusion length at high altitudes, the unknown effects on breakdown of air turbulence and plasma sheaths around the vehicle, and the effects of pre-ionized regions like the ionosphere in which large initial electron densities exist through which the vehicle must pass.

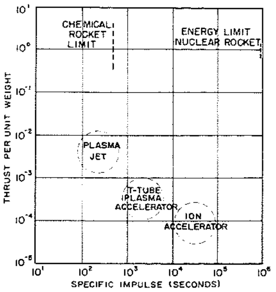


Fig. 5—General rocket characteristics of some plasma propulsion devices.

Plasma Noise

As a result of the interaction between electrons, ions, and neutral molecules in a plasma, electromagnetic energy is generated and emitted by the plasma. This emission of passive radiation from the plasma can be due to a variety of physical processes such as: bremsstrahlung (the deceleration of particles due to an atomic encounter); the release of energy during recombination of an electron-ion pair; Cerenkov radiation from the bow wave formed when particle velocities exceed the velocity of light in the medium; or unstable plasma oscillations arising from gradients of electron density which exist in non-uniform plasmas. The radiated energy is in general noncoherent, varying over a wide, continuous spectrum of frequencies, and thus appears principally as a noise signal.

This noise can impose limitations on the sensitivity of an antenna receiving system by raising the noise level of the environment in which the transmitting and receiving system operates and hence defeats the advantages gained in using masers, parametric amplifiers and other low-noise receiving devices. The noise radiated from a plasma *is not in all cases* necessarily a detrimental effect as it is in communications. Thus, if the spectral distribution of the emitted energy is characteristic of the plasma properties, a measurement of the microwave radiation provides specific information on the plasma. As an example, knowledge of the radiated power gives a measure of the electron temperature in the plasma; this has been used as a powerful diagnostic technique. Further investigations have been focused on the microwave radiation from plasmas produced by hypervelocity bodies in the hope of providing a means for detection and discrimination of such vehicles as they enter the atmosphere.

A major difficulty in the above-mentioned application is an understanding of the fundamental processes. For a plasma in a steady state, macroscopic radiative transfer concepts, without detailed knowledge of the atomic processes, can be applied and the emission spectrum determined from the electromagnetic wave absorption, transmission and reflection properties of the plasma. These determinations are complicated by the nonuniformity and geometrical configuration of the emitting plasma. However, most practical plasmas of interest are not in equilibrium, and as yet a considerable amount of theoretical work remains to be done on nonequilibrium radiation. Furthermore, few reliable quantitative measurements are available to guide the theoretical work.

PLASMA PROPULSION

After a space vehicle has been placed into an orbit out of the reach of strong gravitational forces, by conventional means (e.g. a chemical rocket) there no longer exists a need for a high-thrust device. Electrical propulsion techniques could then take over, to greatly increasing the size of the payload that can be projected into larger orbits.

Basic Thrust Considerations

To show that this is the case, consider some fundamental system parameters of a rocket. The basic parameters are the specific impulse (defined as thrust in *weight-units/propellant-mass flow-rate*) whose units are seconds, and the thrust (*in weight units*) per unit weight, a dimensionless parameter. For a rocket to take off from a planet, its thrust per unit weight must be greater than one. However, in regions where the forces of gravity are small, even small values of thrust/weight may be useful.

In a chemical rocket, the thrust power is limited to the specific energy content within the chemical propellant, so that the highest specific impulse possible is desired. In electrical propulsion, however, the source of the power and the working fluid are completely separate, hence the optimum specific impulse is not necessarily the greatest one. Thus, the source of power increases with increasing specific impulse and the propellant or working fluid decreases with increasing specific impulse with an optimum specific impulse when the sum weight of the propellant and power plant (i.e. vehicle) is minimized. For operations within the influence of the earth's gravitational field, such as a complete round trip of a lunar mission or the establishment of a communications satellite in a stationary 24-hour orbit at a height of 22,500 miles, the optimum specific impulse required ranges from 1500 to 5000 seconds. For interplanetary flights a specific impulse of 7500 to 20,000 seconds is desirable.

These values of specific impulse are beyond the limit of the energy of conventional rocket propellents, so that new methods are required. In Fig. 5 are illustrated the limit of thrust per unit weight and specific impulse of chemical rockets, and the regions of operation of some of the devices to be discussed.

Electrostatic or Ion Propulsion

One technique for attaining a large specific impulse is to electrostatically accelerate a beam of charged particles and expel them at very high velocities. In this manner, it may be possible to design a low-thrust system suitable for space flight. In its simplest form, an ionic rocket would consist of an ion source to supply the fuel, and an electrostatic accelerator, or gun, to accelerate the ions, the ejection of the ions from the device corresponding to the mass flow from an ordinary rocket.

Considerable thought has gone into a choice of fuel for an ionic rocket. The basic requirements are that the ion source yield an ion of sufficient mass (to give an appreciable thrust) and at the expense of a minimum amount of power. Most present experimentation has been with the contact-ionization type of ion source using vapors of alkali metals as the fuel. In this technique, cesium or rubidium, which have very low ionization potentials, are passed through regions of incandescent tungsten (which has a higher work function than either cesium or rubidium). The alkali atoms readily lose their valence electrons to the tungsten and nearly 100-percent ionization can be achieved.

A more serious problem in the development of ion rockets is the space-charge limitation upon the maximum current densities which can be obtained for a particular accelerating voltage, electrode configuration, and propellant. Practical current densities which have been achieved at accelerating voltages below 10 kv are of the order of 12 ma/cm^2 for cesium.

Since ion bombardment can cause serious electrode erosion, secondary electron emission and impact heating, it is necessary to focus the ion beam to overcome the beam spread resulting from the space charge repulsion of the charged ions. To obtain collimated beams, cylindrical-beam and converging-beam Pierce Gun accelerating systems have been studied.

To preserve the electrical neutrality of the ion rocket and to prevent space charge from building up behind the ship and hence inhibit the ejection of ions, it is necessary to neutralize the "exhaust" of the ion rocket. To achieve space-charge neutrality, particles of the opposite charge must be introduced into the exhaust. The entire ensemble, consisting of negative and positive particles and hopefully neutrals due to recombination, is electrically neutral, so in effect it is a *plasma.*

One technique of neutralizing is to inject electrons into the positive ion beam from electron emitters located around the perimeter of the beam. The electrons are attracted into the ion beam by the space-charge fields in the unneutralized portion of the beam and oscillate through the beam, thus giving some degree of neutralization to the ion beam. Since the mass of the electron is a small fraction of the ion mass, an ejection of electrons would make a negligible contribution to the net thrust and are therefore useful solely in an attempt to attain charge neutrality.

A further suggestion of an ion rocket which may overcome the charge neutralization problem is to have the rocket composed of ion diodes each alternately accelerating positive and *negative* ions. The exhaust of such a system would be electrically neutral, and furthermore, if a suitable negative ion of comparable mass to the positive ion were known, then the over-all thrust of the system could be doubled. The difficulty is of course in obtaining a suitable negative ion source. Such a dual ion device is illustrated in Fig. 6.

Other charged masses, such as colloidal suspensions, dust particles, and heavy molecules, have been suggested as possible fuel for an ionic propulsion system and are currently being investigated.

Neutral Plasma or Magnetohydrodynamic Propulsion

High specific impulse devices are possible using a partially or fully ionized gas (i.e. a plasma) as the propellant in which the ion and electron densities are essentially neutral. Such a device is not affected by the space-charge limitations of the ion rocket. Since the plasma is an electrically conducting fluid, electromagnetic fields can be used to interact with it in order to heat the plasma to higher temperatures or to accelerate it to high velocities. Electromagnetic fields can transfer energy to a plasma by two basic methods namely Joule heating which increases the thermal energy of the plasma and by the interaction of the plasma current with the magnetic field which creates a force accelerating the plasma and hence increases the energy of motion of the plasma. The manner in which this force interacts with the plasma is strongly dependent on the geometry of the apparatus and on the plasma properties and is the basis for a number of schemes for plasma propulsion devices.

The plasma arc jet is an example of a device in which a plasma is used to Joule heat a gas. In the plasma jet a d-c voltage is applied between the operating electrodes (Fig. 7a) causing a breakdown of the gas in the chamber. The propelled gas is then forced through this electric arc and is heated upon passing through the arc. After heating, the hot gas is expanded in a conventional nozzle. The limitation of specific impulse in the plasma jet is caused by the inability to recover the energy expended on dissociation and ionization of the gas as it passes through the arc. Unless recombination occurs before the gas is expelled from the nozzle, this energy will not appear as kinetic energy of the gas flow and hence is lost.

A device which minimizes the above losses can be made by accelerating a preheated gas using magnetic fields. In this scheme (Fig. 7b), a hot gas ($\sim$3000°K) is passed into the acceleration chamber where electric currents are caused to flow through the plasma in a given direction. A magnetic field permeates the plasma in a direction normal to the electric current. The action of the current and the magnetic field creates a $J \times B$ (where J is the current density, B the magnetic field) force which accelerates the plasma in a direction perpendicular to both the magnetic field and the electric current.

Considerable experimentation has been performed with the T-tube (Fig. 7c) in which the gas is highly ionized by passing a large current through the head of the T and then accelerating the plasma up the stem of the tube using magnetic fields. Further sophistication of this device is to use additional magnetic fields orientated along the stem of the T which act as magnetic nozzles increasing the velocity of the plasma and, furthermore, keeping it away from the walls of the tube to prevent cooling and erosion. In this manner, specific impulses up to 5000 seconds are possible.

Techniques have been developed on a laboratory scale whereby donut-shaped blobs of plasma or plasmoids can be projected by magnetic forces at speeds exceeding 10^{7}cm/sec. Such a plasma gun constitutes another possible means of propulsion.

As the interaction between magnetic

fields and plasmas becomes better understood, a greater and greater number of novel propulsion techniques will be suggested, and some will inevitably prove practical.

PLASMA DEVICES

Many years before the full importance of plasmas in the field of science was realized, devices employing plasma were in operation. These devices, of course, did not require a detailed understanding of plasma properties, and included the fluorescent lamp, noise sources for the calibration of radio receiving devices and as laboratory standards and transmit-receive tubes for radar applications. The fluorescent lamp, for example, is just a gaseous-discharge plasma whose light emission is used to activate the fluorescent material coating of the light tube. Most noise sources for laboratory calibrations are also gaseous discharges operating well below the plasma frequency in the opaque region. In radar systems, on the other hand, it is necessary to have a switch to disconnect the receiver from the transmission line during the transmitted pulse and to disconnect the transmitter the rest of the time. Such a switch can be obtained using appropriately connected spark gaps which break down during transmission and act as a low-impedance device, while normally they are high-impedance open circuits. The T-R tube is merely a sophisticated spark gap which operates at lower voltages (since the gas in the tube is at low pressure) and whose properties are not affected by external environment conditions such as humidity and temperature.

The ignitron, the mercury rectifier, and the common gas voltage-regulator vacuum tube are examples of other important plasma devices that have been known for some time.

Microwave Devices

Promising applications of the properties of plasmas appear in the field of guidance and generation of high-radio-frequency energy. Since a column of plasma will support the propagation of various field configurations of electromagnetic waves, a considerable effort is presently being devoted to an understanding of *plasma waveguides*. The waveguide is the basic component of the microwave system, and its characteristics will determine and limit the other microwave devices which are possible. Since a plasma waveguide exhibits specific mode and bandpass characteristics (which can be controlled by external magnetic fields), waveguide filters are obvious applications. An electromagnetic wave travelling down a plasma column will have its phase and amplitude altered depending on the plasma properties and configuration. Prototype attenuators and phase shifters have been built in several laboratories. Plasma properties can also be used for waveguide switching. In addition, since plasmas exhibit interesting properties such as the Faraday effect, polarization characteristics, double refraction and non-linearity, they present a host of phenomena that can be utilized for circuit and microwave applications.

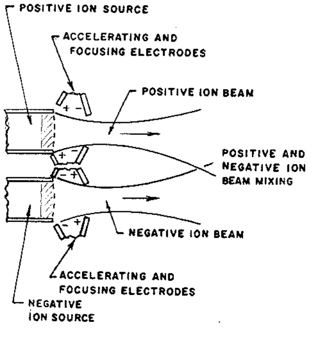
It has been demonstrated that slow electromagnetic waves can propagate in a plasma cylinder in the presence of a dc magnetic field. As a consequence, intense investigations are being made in attempts to utilize a plasma as the slow-wave structure of travelling wave tubes. In this manner, the characteristics of the slow wave structure can be altered externally by changing the plasma properties. By using modulated electron beams passing through a plasma, a growth of the modulation has been observed. This has stimulated interest in the possibility of obtaining microwave amplification by such techniques. Suggestions have been put forth in which the non-linear effects of a plasma at high power levels is utilized as the non-linear propagating medium of a parametric amplifier. The generation of millimeter waves by plasma techniques, such as high-intensity arcs and harmonic generation (where the plasma provides the non-linearity), and excitation of coherent plasma oscillations and their conversions to short wavelength radio waves, is another field of great interest and current importance.

Further schemes have been put forth whereby the ion sheaths surrounding hypersonic re-entry vehicles would be utilized as coherent radiative elements and hence as a plasma antenna; however, considerably more work is still required in this direction.

Electric Power Generation

If a dc magnetic field is applied in a direction perpendicular to a moving conducting fluid, an electric field is generated in a direction normal to both the magnetic field and the fluid flow. If, now, electrodes connected to an external load are appropriately placed, the electric field will cause a current to flow in the external circuit (as well as in the plasma). Energy is transferred to the load at the expense of the kinetic energy of directed motion of the conducting fluid. This is the basis of the dc magnetohydrodynamic generator. The advantages of such magnetohydrodynamic (MHD) devices are that no moving parts, only a moving fluid, is required. The difficulties include characteristics of the working fluid (ionization and dissociation potentials, heat-transfer properties), the methods of achieving adequate flow velocities, geometry, contamination and corrosion problems. MHD generators have also been proposed for ac power generation as well. These devices can be either pulsed or steady-state.

Fig. 6—Positive and negative ion accelerators to achieve space-charge neutrality in exhaust of an ion rocket system.



A plasma device for the conversion of heat into electricity is the thermionic diode in which some of the electrons liberated from the cathode have sufficient energy to overcome the internal work function of the cathode and proceed to the anode where they lose their kinetic and potential energy. If the resulting energy level of the electrons in the anode is more negative than the original energy level at the cathode, then the device is capable of driving a current through a load and hence do useful work by this conversion of heat into electricity. The most serious limitation of such a scheme is the space charge of electrons which builds up near the anode and which inhibits electrons emitted from the cathode from reaching the anode. One technique of overcoming the space-charge problem is to introduce cesium vapor into the device, which upon contact with the hot anode becomes a positive cesium ion and hence tends to neutralize the negative electron space charge. Other suggested schemes for controlling the charge effects include the use of a grid as a third control element and the use of crossed electromagnetic fields. Considerably more study is required on anode work functions under operating conditions, materials to withstand the high temperatures required at the cathodes as well as on the space charge problem.

Semiconductor Microplasmas

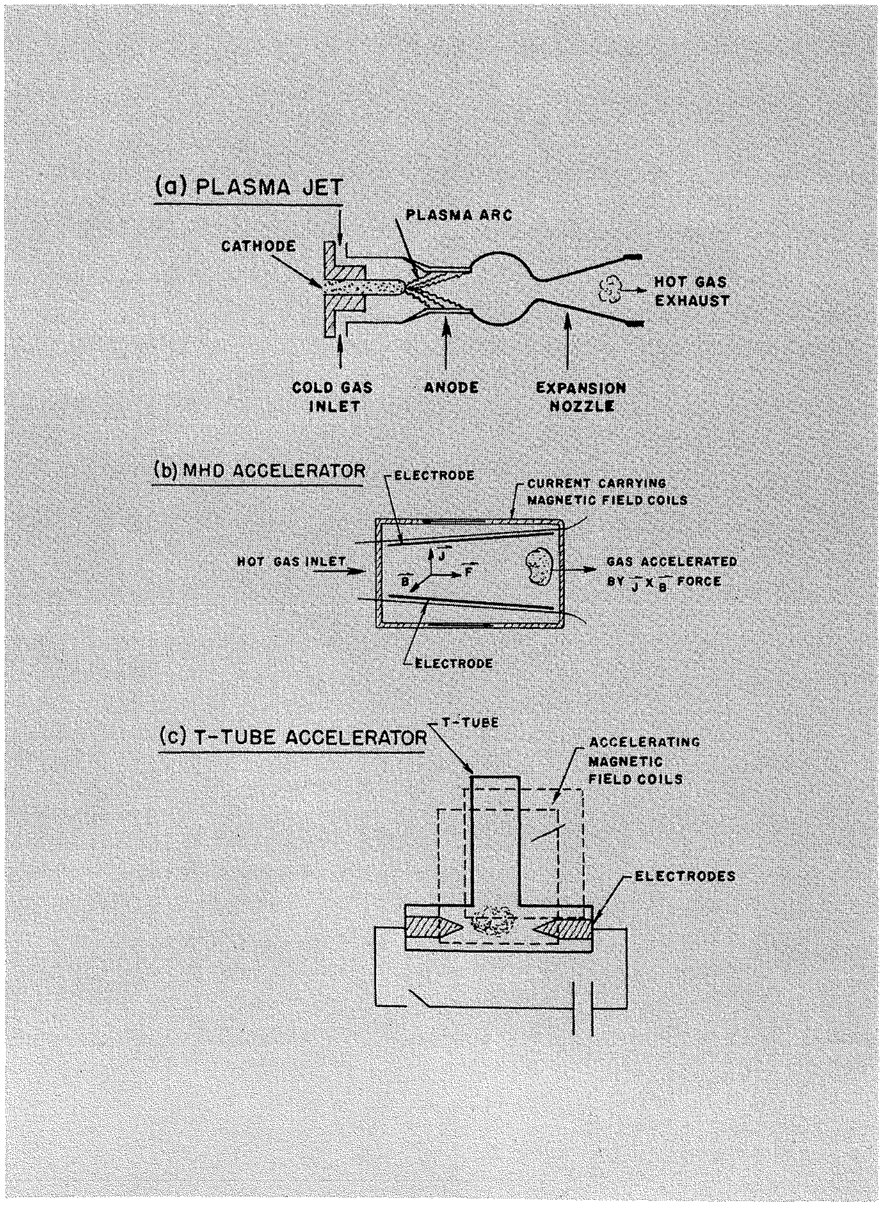
A good analogy exists between the process of electrical breakdown in a low-density gas and the avalanche effect which occurs in some reverse-biased semiconducting diodes. In these devices, a slight increase in the reverse voltage above some critical value causes a very rapid increase in current, and the junction is said to break down. The breakdown occurs because of the multiplication and resulting avalanche of the charge carriers, both positive (holes) and negative (electrons), in the depletion layer of the device in a manner analogous to the creation of ionization by electrons in a gaseous discharge. Observations indicate that the breakdown occurs in very minute highly ionized regions, or *microplasmas,* of about 500 angstroms in diameter. Such devices are of great practical potential for applications which require switching times of millimicroseconds.

The above are only a few of the devices and applications for which plasmas are suitable. The current intense investigations on the properties of plasmas will undoubtedly result in an "avalanche" of further practical uses.

THE FUTURE

Today, plasma physics is a challenging field of research with many problems and few satisfactory solutions. It encompasses many disciplines, including particle physics, physical electronics, aerodynamics, radiation physics, electromagnetic wave theory, magnetohydrodynamics, thermodynamics, spectroscopy, physical chemistry, quantum mechanics, and many others. The interplay between these various fields of study cannot help but further the frontiers of science.

Fig. 7—Schemes for accelerating a plasma for use as propulsion devices. A) A plasma arc is used to heat a gas to high temperatures. The gas is then passed through an expansion nozzle and forms a high-velocity exhaust. B) In the magnetohydrodynamic accelerator, an ionized gas is passed through crossed electric and magnetic fields, which accelerate this plasma. C) In the *T*-tube, the energy stored in a capacitor bank is discharged into a gas, creating a plasma which is accelerated up the stem of the *T* using magnetic fields.



As, slowly and surely, solutions are found to the many pressing problems of plasma physics, *what can we hope to achieve?* The promise of the future includes a better understanding of the creation of the Universe and the forces at work in it, an almost inexhaustible supply of electrical power using thermonuclear fusion reactions, reliable communications with space and re-entry vehicles, propulsion devices appropriate for interplanetary travel, devices for producing and amplifying high-frequency radio energy, electrical generators with no mechanical parts, and numerous new semiconductor devices. These are the goals of plasma physics research.

The immediate future must be devoted to a better understanding of the behaviour of plasmas and related phenomena under various conditions. The most significant progress is thus most likely to be made in fundamental studies under controlled conditions. Application of the basic knowledge gleaned in this manner can then follow immediately. The present problems are certainly formidable, but the richness of the rewards for their solution warrant the interest and effort which is and will be devoted to plasma physics.

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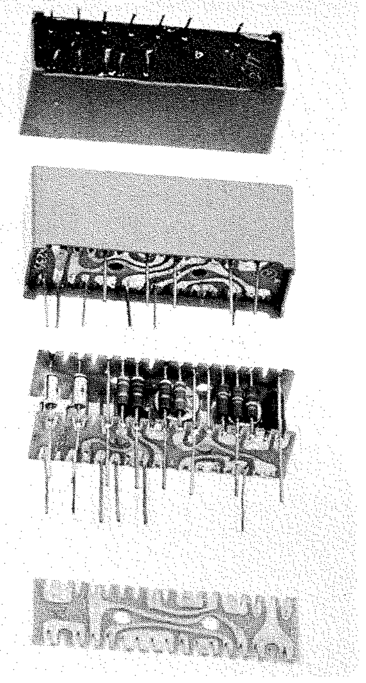


Fig. 1—The new module design, showing assembly steps before placing on plug-in card. Completed unit at top shows leads emerging from encapsulation.

NEW DESIGN FOR MINIATURE MODULES

by **A. C. CORRADO and J. W. SMILEY**
Surface Communications Division
DEP, Camden, N. J.

THE MUSHROOMING application of the miniature module to electronic equipment design demands new modules that are economical, reliable, and readily mass-produced—often with a maximum amount of automation in manufacture.

As a result of a design and development program conducted by the authors, a new module has been engineered that satisfies such requirements better than older types. This module (Fig. 1) was designed for data-processing applications where low power dissipation is a characteristic. In equipment of high power drain, miniaturization with such modules depends, of course, upon the cooling requirements.

BACKGROUND

The problem of modularizing a military data-processing equipment that had a high production potential, and circuits designed to exacting military environmental standards, led to development of the new module. (In this context, modularization may be defined as the packaging of components with self-contained printed circuitry in the highest density and minimum volume.) Available module types were investigated and found inadequate. Of those investigated, the least objectionable was the so-called piggyback design (Fig. 2), where components are superimposed with the leads bent U-shaped and protruding through holes in a printed board. The unit is then placed in a rubber mold and encapsulated, or potted.

The piggyback type had disadvantages: 1) component leads had to be preformed to match holes in the printed board by a slow (expensive) hand operation; 2) leads had to be fed through the tiny holes by hand; and 3) rubber molds used during encapsulation deteriorated quickly, and thus were short-run items not easily quality-controlled.

The design of the new module overcomes these disadvantages and achieves additional positive features.

ADVANTAGES OF THE NEW MODULE

The new miniature module design has a number of important features that enhance its quality, simplify its mass production, and reduce its unit cost.

Preforming of the leads is eliminated by the new technique of vertically mounting the components, sandwiching them between two printed boards with the leads crimped into V-shaped slots (Figs. 1, 3 and 4).

The tedious feed-through operation is eliminated by the V-shaped slots. Placing of the leads in the notches can be programmed for automation, and any diameter lead can be inserted. The minimum of component handling resulting promotes greater reliability.

A new standard-sized epon-resin shell serves as both potting container and final housing, eliminating the rubber molds and allowing rigid quality control. Additional features are 1) provision of two 0.125-inch holes in the printed boards to facilitate flowing of the potting compound and lessen air entrapment, and 2) coating of the glass seals on transistors and diodes to prevent their cracking. The shells are color-coded and numbered for ready identification.

STANDARDIZATION AND PRODUCTION

The size of the printed boards and complete module, the component types, and the number of modules per mother board (Fig. 5) are all amenable to standardization. The different circuits contained in the modules were designed for general low-speed logic applications and were selected to fit the requirements of data-processing equipment (Figs. 3 and 6).

Printed-board size was dictated by the following components: *transistors*, 2N404 (selected) and 2N1301; *resistors*, RCA 722300, 5-percent carbon composition; *diodes*, RCA 8950093-4, IN695; and *capacitors*, RCA 8980838, DM 15 5-percent, 100wv.

Module size was predicated on 1) positioning of transistors for proper stress relief of leads, 2) component tolerances, and 3) location of the leads on a 0.10-inch grid on the mother board. Each printed board contains 34 notches, 17 on each side. A universal tool cuts out the board to size and punches the 34 notches in one operation. Every board is punched out and notched identically, regardless of circuit application. A simple assembly technique is used for the new module (Fig 4).

TESTING

To expedite electrical testing of the new module, the devices illustrated in Fig. 7 were designed. Over-sized plug-in holes are used, with female connector inserts filled with powdered graphite. The holes were arranged to match up with the leads of different modules. The female inserts are connected to the test circuitry, which comprises logic circuits. The tester is operated by a rotary switch and a push button which activates a lamp-indicator. An oscilloscope may be used instead to display test results.

SUMMARY

This new miniature module achieves low unit cost and reliability through its simplified assembly, potting, and testing techniques. Its design is very amenable to standardization, and DEP Central Standards Engineering has accepted it as such. Over 25,000 of these modules are in mass production in Camden, and the design concept of the module is being adopted by a number of engineering groups.

ACKNOWLEDGEMENT

The authors would like to credit P. J. Anzalone, J. Liebermann, R. D. Torrey, and P. K. Hsieh for their work on the circuit designs; also, the Camden Plant Printed Wiring Activity for assembly-line design and the DEP Test Equipment Activity for the production-line tester.

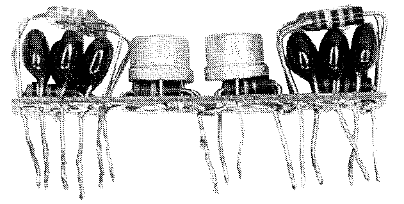
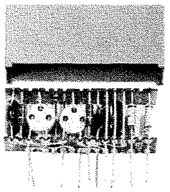
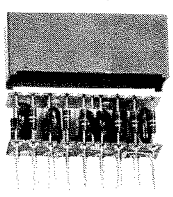


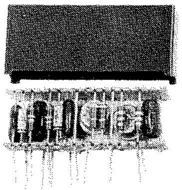
Fig. 2—A typical piggyback module, an older type in which components are mounted in layers.



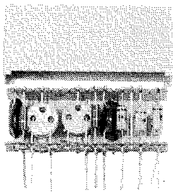
a. 2 x 2 input gate.



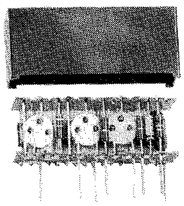
b. flip-flop gate.



c. low-frequency flip-flop.

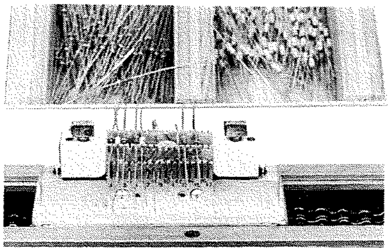


d. 2 x 3 input gate.



e. one-shot, Schmitt trigger.

Fig. 3—Five of the new standard-size modules, before potting. Color-coding is used for identification.



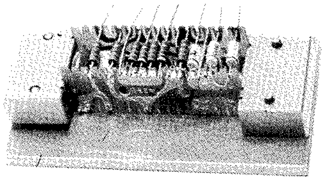


Fig. 4—Left: Assembly jig on production line. Embryonic module is passing a bin of components during assembly. Below: assembly jig used during engineering development work.

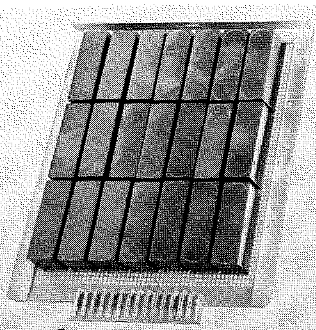


Fig. 5—Plug-in card, or mother board, of 21 modules for a military data processing equipment.

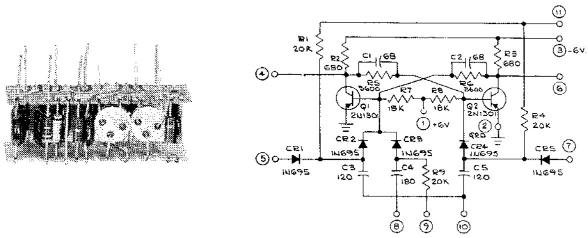


Fig. 6—Component layout and circuit diagram of medium-speed flip-flop module shown at top left.

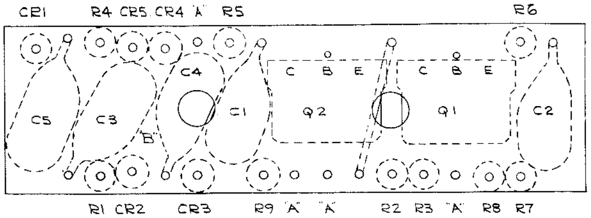


Fig. 7—The authors, A. C. Corrado (left) and J. W. Smiley operate the production-line tester. A module is shown in position (arrow). Inset: tester used during engineering development work.

J. W. SMILEY received the BSEE from Lafayette College in 1952 and has since undertaken graduate studies at University of Pennsylvania and Rutgers University. Joining RCA in 1953, he was engaged in military television systems work, including design and development on a transistorized image orthicon camera, and was involved with studies of military grid communications and stabilized platforms for military television. In 1956, he was assigned to the AN/GKA-5 program, where he participated in design, development, fabrication, type-testing and field evaluation. He has been engaged in miniature module development, design, and fabrication techniques since 1958. He is a Member of the IRE.

ANGELO C. CORRADO received the BSME from Drexel Institute of Technology in 1955 and is presently studying for the BSEE at Drexel. Upon graduation, he joined the Airborne Systems Division, working on the signal data and range computer for radar fire-control system AN/ASG-14. In 1957, while with Broadcast Equipment Engineering, his work included the redesign of the TM-21A color monitor and design of the TS-40 transistorized video switches. He transferred to SurfCom in 1958, where he did design and development work on a miniature telemetering receiver and transmitter. Thereafter his work included mechanical design for DEE. He is now engaged in miniature-module design, development, and fabrication techniques.

OPTICAL MASERS

Ever since the first demonstration of microwave amplification by the use of stimulated emission, there has been speculation as to whether or not the maser concept could be successfully applied in the infrared and visible portion of the electromagnetic spectrum. As early as 1956, R. H. Dicke proposed[1] a means of making an ammonia-beam maser in the infrared, using the rotational energy levels of the ammonia molecule. In the past few years, people have been optimistic about extending maser techniques into the visible portion of the spectrum. The basic principles underlying all masers—microwave, infrared, and visible—are the same,[2] but the problems that arise in achieving practical embodiments of the maser concept differ radically as one goes from the microwave frequency region (10^9 to 10^{11} cps) to the visible range (frequencies of 10^{14} to 10^{15} cps). These concepts are discussed here, as is the current state of the art and some possible applications.

by **DR. J. P. WITTKE**
RCA Laboratories
Princeton, N. J.

DR. JAMES P. WITTKE received the degree of Mechanical Engineer from Stevens Institute of Technology in 1949. After a year and a half spent studying hydrodynamic forms as a Fellow at the Experimental Tuning Tank in Hoboken, New Jersey, he entered the graduate school of Princeton University. Here he studied in the physics department, receiving an M.A. degree in 1932, and the Ph.D. in Physics in 1935. Dr. Wittke taught for one year as instructor in Physics at Princeton before joining the Technical Staff of the RCA Laboratories in Princeton. Since coming to RCA Laboratories, he has been engaged in work on microwave masers and on coherent optical scattering processes. He is presently working on optical masers. He is a member of the American Physical Society, Sigma Xi, IRE, and Tau Beta Pi.

TWO EXAMPLES will illustrate the changes required in increasing the frequency by four orders of magnitude —i.e., in going from the microwave to the visible range of the spectrum.

One is the *resonant structure* required to concentrate the electromagnetic field. At microwave frequencies, wave lengths are of the order of a centimeter, and cavities can be built that are one, or at most a few, half-wavelengths long. The modes of the resonator are generally well resolved, and it is no problem to couple the emissive material to the desired cavity mode. Optical wavelengths, on the other hand, are so small that it is impossible to build useful structures a few wavelengths across, and much larger structures must be employed. These large structures can be expected to sustain many modes very close together in frequency and of comparable Q. Moding may thus be a serious problem in optical masers, whereas it is not of concern at microwave frequencies.

A second example of a new problem arising at optical frequencies is that due to *spontaneous emission.* Atoms in excited states tend to return to their lowest energy (ground) state by the emission of radiation. This process has two harmful effects in a maser: it provides an alternative method of de-excitation, reducing the size of the population excess in the upper state; and the spontaneously radiated energy, being incoherent with the signal wave field, is an additional source of noise in a maser amplifier or oscillator.

Neglecting possible coherence effects in spontaneous emission, a system having N_2 atoms in excited states will lose energy by *spontaneous* emission at a rate (P_{sp}):

$$P_{sp} = \frac{4\omega^4 \mu^2 N_2}{3c^3} \qquad (1)$$

Where: ω is the circular frequency of the radiation, μ is the dipole moment associated with the transition between the ground and excited states, and c is the velocity of light.

By comparison, the power (P_{st}) radiated by a system with ΔN atoms in the "excess" upper state population due to *stimulated* emission is:

$$P_{st} = \frac{\hbar\omega}{\Delta\omega}\left(\frac{\mu E}{\hbar}\right)^2 \Delta N \qquad (2)$$

where $\hbar = h/2\pi$, h is Planck's constant (6.624×10^{-34} joule-sec), E is the strength of the electric vector in the electromagnetic field inducing the transition, and $\Delta\nu = \Delta\omega/2\pi$ is the spectral width associated with the response of the atom to the field ($\omega/\Delta\omega$ is an effective atomic Q for the transition.)

The important point to note from equations 1 and 2 is that the relative importance of spontaneous emission

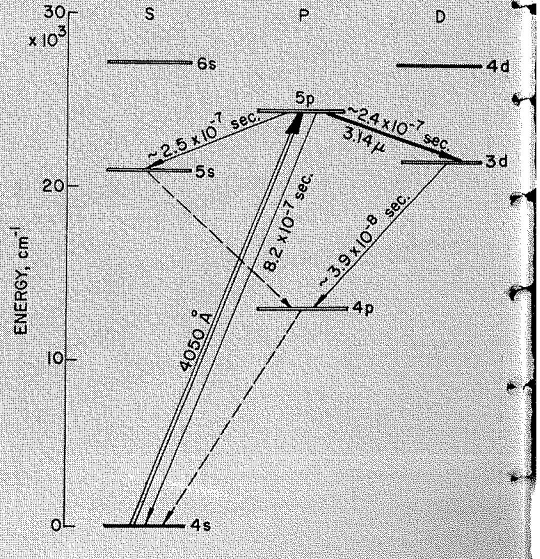


Fig. 1—Energy levels associated with the excitation of the valence electron of a potassium atom in the vapor.

varies as the cube of the frequency. Thus, it is of the order of 10^{12} times as important at optical as at microwave frequencies.

Another difference between optical and microwave masers is in the nature of the internal energy states that are utilized. Microwave frequencies correspond to energies of the order of 10^{-4} electron volts; internal energy states separated by such energies can be found associated with orientational energies of intrinsic electronic magnetic moments in laboratory-scale magnetic fields, (a few thousand gauss). The atoms are thus acted on by microwave *magnetic* fields to produce the desired transitions. Transitions corresponding to optical radiation, on the other hand, have energies of the order of an electron volt. These much more energetic transitions are associated with changes in the state of motion of electrons in atoms and are generally brought about by the action of the *electrical* component of the radiation field.

EXCITATION METHODS

Several methods have been proposed to bring about the required emissive inverted population distribution in an optical maser. As mentioned, Dicke has shown that molecular beam maser techniques can be extended into the infrared. Others have proposed optical masers using three or more energy levels.

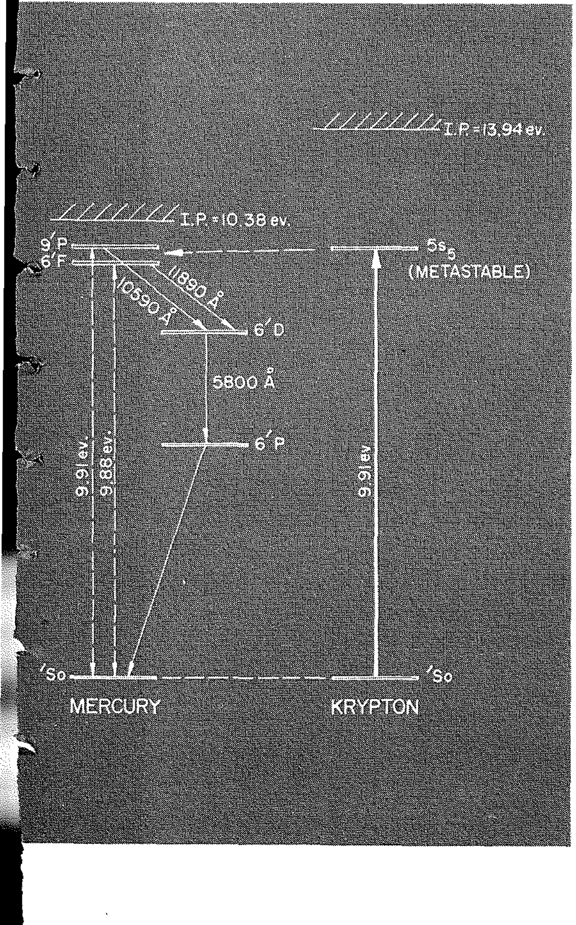
In one such scheme, proposed by Schawlow and Townes,[3] the energy levels are those associated with the excitation of the valance electron of an alkali metal atom in the vapor (Fig. 1). Here, radiation at a higher frequency than that of the desired signal excites atoms from the ground state to some excited state, from whence they decay to states of lower excitation, eventually returning to the ground state by a series of one or more spontaneous emission processes.

In general, several alternate decay modes are available to an atom in an excited state; for example, referring to Fig. 1, a potassium atom excited to its $5p$ state can decay to the $5s$, $3d$, or $4s$ states. Various different decay rates are associated with these competing, alternative processes. In the case illustrated, an atom excited to the $5p$ state has roughly equal probability of decaying to the $5s$ and $3d$ states, while it is considerably less likely that it will decay directly to the ground state. (Only about one atom in eight returns directly to the ground state.) Atoms which decay to the $3d$ state are rapidly removed from this state by decay to the $4p$ state. Thus, when potassium atoms are optically excited to the $5p$ state, spontaneous decay processes tend to build up a population distribution such that there are more atoms in the (relatively long-lived) $5p$ state than in the (quickly decaying) $3d$ state. Schawlow and Townes therefore suggested that this optical pumping process might be used to set up an emissive condition in the vapor for the 3.14-micron infrared radiation coupling this pair of states.

A basic difficulty of this method of obtaining an emissive state is associated with the spectral sharpness, or narrow bandwidth, associated with these optical vapor-phase transitions. Because the spectral lines are so sharp, it is very difficult to get an excited lamp that can produce much pumping radiation in the narrow band of frequencies necessary to excite an atom to the desired state.

Because of this, alternate methods of excitation of gas atoms have been proposed. One, by Sanders,[4] utilizes electron bombardment in a gas discharge. Here basically the same processes would occur, except the excitation would be by transfer of part of the kinetic energy of the hot electrons in the discharge to the gas atoms connected with the maser action. There is one additional complication in this scheme, in that presumably the electrons would tend to excite atoms into the lower, as well as the upper, maser level.

Fig. 2—A method of indirect electron-collision excitation of a maser gas (mercury vapor) by mixing it with a more dense auxiliary gas (krypton) in an r-f discharge.



To obtain a greater population excess in the upper of a pair of energy states than one might expect from either of the aforementioned ways of exciting a gas, Javan[5] and others have suggested yet another scheme. This also involves the use of electron-collision excitation. However, now the maser gas is not excited directly. The maser gas is mixed with a different gas of much higher pressure that has the following properties: it has a metastable state of long lifetime that requires the same amount of excitation energy as an excited state of the maser gas. A possible combination is shown in Fig. 2, where mercury vapor is the maser material and krypton is the more dense auxiliary gas. The electrons in the gas discharge excite the metastable $5s_5$ level of krypton. Because of the long lifetime of this state, an appreciable number of atoms are built up in this state. There is therefore a good chance that one of the mercury maser atoms will collide with an excited krypton atom, and since the 9^1P and 6^1F states of mercury have nearly the same excitation energy as the krypton atom, there is a high probability that in a collision there will be a resonant transfer of energy between the atoms. As a result of such a collision, the krypton atom is de-excited, and the mercury atom is left in either the 9^1P or 6^1F level. Maser action may then take place between one of these states and a lower, unpumped level such as the 6^1D state shown.

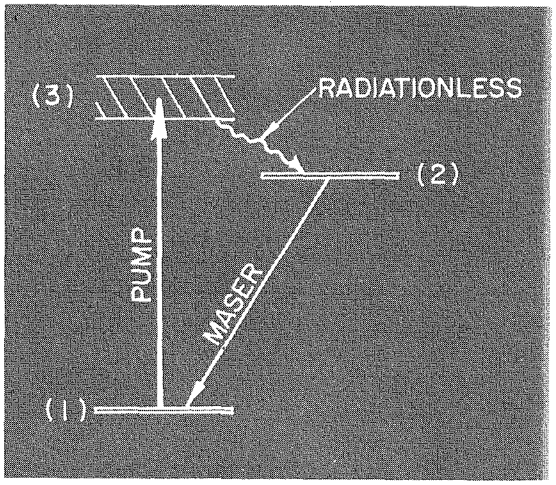


Fig. 3—Energy-level scheme utilizing a solid (e.g., ruby) instead of a gas.

There is another way in which the difficulty associated with narrow spectral lines in the optically pumped vapor scheme can be avoided. If instead of a gas, a solid is used, it is possible to find fluorescent centers that have an energy-level structure such as shown in Fig. 3. Here state *1* is the ground state, state *2* is a relatively long-lived state connected to the ground state by a sharp optical transition, and state *3* is a broad state into which atoms can be excited by radiation at any frequency in a broad absorption band. In certain solids, such as ruby (chromium-doped aluminum oxide), this energy scheme can be found; moreover, a chromium ion excited to the broad level *3* decays rapidly (and in a *radiationless* fashion) to state *2*. Thus radiation in a broad band excites atoms from the ground state to state *2* via the short-lived state *3*. If the excitation rate is high enough, this process can depopulate state *1* and populate state *2* sufficiently that maser action can be obtained between states *2* and *1*.

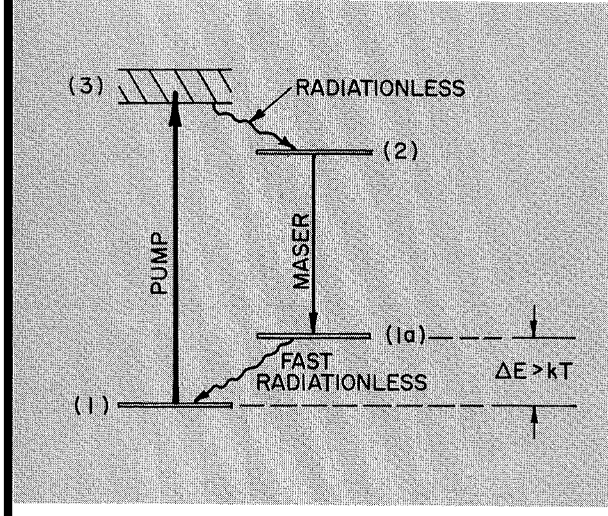


Fig. 4—Energy level scheme utilizing a solid with an additional short-lived energy level (1a).

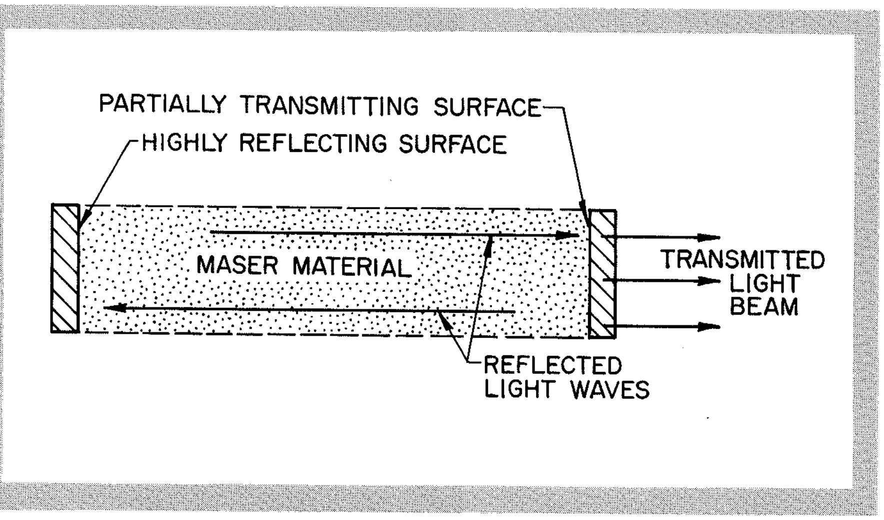


Fig. 5—A high-Q resonator for an optical maser—a pair of Fabry-Perot plates.

Because in this scheme state *1* is the ground state and hence initially contains all the atoms, it requires a very intense exciter lamp to obtain the necessary population inversion. However, if the solid has an additional short-lived energy level, sufficiently far above the ground state that it remains essentially depopulated, the situation is considerably improved. This is illustrated in Fig. 4. Here, a new level (state *1a*) lies $\Delta E > kT$ above the ground state, kT being the average thermal excitation energy at temperature T. Now maser action can occur between states *2* and *1a* without the ground state being heavily depopulated, since both states participating in the maser action are normally depopulated. A sufficiently rapid decay from *1a* to *1* is, of course, required. Several solids meet these requirements, such as calcium fluoride doped with uranium, and calcium fluoride doped with samarium.

OPTICAL MASER CHARACTERISTICS

If an electromagnetic wave propagates through an emissive medium, the amplitude of the wave will grow exponentially with distance until saturation effects make the system non-linear. Such an emissive medium thus acts as a traveling wave amplifier, with a gain G given by:

$$G = \exp(\alpha L) \tag{3}$$

Where: L is the length of the amplifier, and α is the gain coefficient. This is related to the parameters of the maser material by:

$$\alpha = \frac{4\omega\mu^2 \Delta N}{hc\Delta\nu} \tag{4}$$

Instead of using dipole moments μ, spectroscopists frequently express the strength of optical transitions in terms of oscillator strengths f. These are related to the dipole moments by:

$$f = \left(\frac{2m}{he^2}\right)\omega\mu^2 \tag{5}$$

where: m and e are the electronic mass and charge, respectively. In terms of oscillator strengths:

$$\alpha = \left(\frac{2e^2}{mc}\right)\left(\frac{f\Delta N}{\Delta\nu}\right) = 1.68 \times 10^{-2}\left(\frac{f\Delta N}{\Delta\nu}\right) \tag{6}$$

For narrow optical transitions in solids, typical values for f and $\Delta\nu$ are $f \approx 10^{-6}$, $\Delta\nu \approx 10^{10}$ cps. This gives $\alpha \approx 10^{-18}\,\Delta N$. Since ΔN is not apt to exceed 10^{+18}, (and even this is quite an optimistic value), the need for a field-concentrating resonant structure to increase the effective optical path in any device of practical size is readily seen.

A high Q resonator that appears quite suitable for use in an optical maser is a pair of Fabry-Perot plates.[1,3] Such a resonator is illustrated in Fig. 5. Radiation, essentially in the form of a (limited-extent) plane wave can bounce back and forth between the mirrored surfaces for many times, enhancing its interaction with the maser material. One of the plates is slightly transmitting, permitting a small amount of the energy incident on this end to be coupled out into a useful beam.

The exact behavior of an oscillator formed by making the silvering of the Fabry-Perot plates dense enough to supply the required positive feedback is very complex and has not yet been treated in detail. Schawlow and Townes give plausible arguments showing that one might expect a spectral purity of the emitted radiation of the order of:

$$\delta\nu = \frac{4\pi h\omega(\Delta\nu)^2}{P} \tag{7}$$

where: $\delta\nu$ is the width of the oscillator spectrum, and P is the emitted power from the oscillator. Inserting reasonable values into this equation, it appears that spectral widths of a few cps might be expected. Since optical frequencies are in the range 10^{14} to 10^{15} cps, this corresponds to fantastic spectral purity and, if achieved, would permit a variety of applications (some of which will be discussed later).

In addition to this extreme monochromaticity, which corresponds to a coherence length of the order of 50,000 miles, a maser oscillating in a single plane-wave Fabry-Perot mode would have an output beam limited in directivity by diffraction effects at the output Fabry-

Perot plate. For a resonator diameter of the order of an inch and a wave length of 7500 angstroms, diffraction effects would limit the beam to one diverging at an angle of 3×10^{-5} radians. This high degree of spatial coherence in the wave front corresponds to an illuminated spot diameter of about one yard at a distance from the maser of twenty miles.

PRESENT STATE OF THE ART

With a field that is as rapidly moving as this, it is dangerous to assume that any description of the state of the art will not be outdated by the time of publication. Nevertheless, an attempt will be made.

Work on an optically-excited alkali vapor maser is underway at Columbia University. Various electron-excitation schemes are being studied at a number of places, notably at the Bell Telephone Laboratories and at the Technical Research Group. The workers at Bell have recently been successful in operating an electron-excited gaseous optical maser.[6]

With optically-excited solids, Maiman[7] (at Hughes) reported maser action in ruby during mid-1960, and since then several groups, including one at RCA Laboratories, have repeated and extended Maiman's work with ruby. In many of the experiments with ruby, a ruby rod polished to have plane parallel ends, which are silvered to act as Fabry-Perot mirrors, was excited by being placed inside a helical photoflash lamp. The brilliant flash of the lamp inverted the populations of the ground and long-lived excited states in the ruby, and for a few hundred microseconds (while the flash tube was on), coherent stimulated emission was observed from one partially transparent end of the ruby rod. Other flash lamp-sample configurations have also been used successfully.

Because of the disadvantage of using the ground state as the lower maser state, considerable work is underway at many locations, including RCA Laboratories, to discover other maser materials without this disadvantage. Workers at IBM have recently reported[8,9] two such materials.

OUTSTANDING PROBLEMS

Although the past few months have produced striking advances in the optical maser art, many problems remain. Some of these are illustrated by the ruby masers that have been operated. In ruby, the workers at Bell find[10] that the maser oscillation is not continuous during the exciting pulse, but occurs in short, quasi-random bursts of about one-microsecond duration. The cause of this behavior is not known, nor is its cure. Moreover, although peak maser powers of the order of ten kilowatts have been reported, the corresponding spectral purity given by equation 7 has not been attained, or even closely approached. Equation 7 would give a linewidth of well under one cps. However, because the radiation occurs in microsecond-long pulses, one would expect a linewidth of the order of 10^6 cps. Instead, however, spectral widths of the order of 6×10^8 are the narrowest that have been observed. Also, instead of a diffraction-limited beam angle, angular divergences some twenty times as large are observed. While plausible explanations can be given for some of these apparent discrepancies, it has not yet been shown experimentally that the postulated causes of non-optimal behavior are in fact the actual ones.

Thus far, only pulsed operation of solid state optical masers has been reported, although the pulse lengths have been extended to a point where continuous operation requires but little improvement. Of the solid state masers, two exhibit the "short-burst" type of operation, while one (Sm^{2+} in CaF_2) shows no evidence of this rapid uncontrolable amplitude modulation. It is not yet known why the various materials do or do not show the "burst" type of oscillation modulation. (The gaseous maser that has been operated is also free from this type of modulation.)

POSSIBLE APPLICATIONS

The applications that one can foresee for optical masers depend primarily on the coherent nature of the interaction. This is responsible for both the spatial and temporal coherence of the radiation pattern from a maser oscillator, and the virtues of such devices are closely tied to these properties. For example, because of the high directivity, corresponding to an antenna gain of the order of 10^{10}, optical masers open up the possibility of optical point-to-point communications systems that may be extremely important in space communications. Moreover, the narrow beam permits optical radars of much higher directional resolution than microwave radars. The monochromaticity of an optical maser offers the promise that heterodyne information-handling techniques may be extended to visible frequencies, where the extremely high frequencies are associated with bandwidths many orders greater than available at lower frequencies. As an indication of possibilities in this line, "optical waveguides" that could in principle transmit all the telephone channels between two large cities in one small pipe are under consideration. These are, of course, far from realization in a system at present.

Another class of applications is also dependent on the spatial coherence of the optical maser. The energy from a 1-watt maser could be focused to a spot 10^{-4} centimeters in diameter, producing at the focal point power densities of 100 megawatts/cm.^{2} The optical-frequency electric fields associated with such power densities are of the order of 30,000 volts/cm. It is clear that such fields and power densities can produce chemical and physical reactions in matter under conditions that cannot be duplicated by any other technique. Thus, optical masers may play an important role in molecular electronics technology and microchemistry.

It is difficult to foresee all the possible applications of a device with such radically different characteristics at such an early state of its development; but, it can be seen that optical masers may find uses in the areas of activity in which RCA is engaged.

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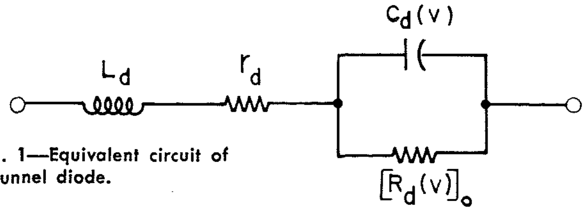


Fig. 1—Equivalent circuit of a tunnel diode.

TUNNEL-DIODE MICROWAVE OSCILLATORS

by **D. E. NELSON and Dr. F. STERZER**
Microwave Tube Advanced Development
Electron Tube Division
Princeton, N. J.

TUNNEL DIODES are heavily doped p-n junctions that exhibit an incremental negative resistance at a small forward dc bias[1-3]. These diodes hold great promise for high-frequency applications because they are not limited by transit-time effects, even at microwave frequencies.

Previous authors have described tunnel-diode oscillators with microwatt power outputs and have derived the conditions for self-starting oscillations in simple oscillator circuits.[3-5]

This article discusses the use of tunnel diodes in uhf and microwave oscillators with milliwatt power outputs, and describes diode performance parameters for oscillator circuits. A lumped-circuit oscillator is analyzed with special attention to the steady state, and a number of practical oscillator circuits and experimental results are presented.

TUNNEL-DIODE PARAMETERS

An approximate equivalent circuit for an encapsulated tunnel diode consists of three elements connected in series: an inductance L_d, a resistance r_d, and a voltage-dependent resistance $[R_d]_0$ shunted by a voltage-dependent capacitance C_d, as shown in Fig. 1. The L_d results mainly from the inductance of the housing; r_d is the resistance of the ohmic contact, the base, and the internal leads of the package. $C_d(v)$ is the junction capacitance, and $[R_d(v)]_0$ is the total resistance of the junction.

The d-c bias voltage V_d across a tunnel diode is given by:

$$V_d = I_d r_d + I_d\,[R_d(v)]_o \qquad (1)$$

Where I_d is the direct current through the diode. At a reverse current an order of magnitude greater than I_p, the resistance $[R_d]_0$ is usually very small compared to r_d, so that r_d can be measured directly. When r_d is known, $[R_d]_0$ can be determined from the current-voltage characteristics of the diode.

Fig. 2 shows the current-voltage characteristics of typical germanium and gallium-arsenide tunnel diodes. In each of these diodes, $I_d r_d$ is much less than V_v (valley voltage) for $O < I_d < I_p$ (peak current), and, therefore, V_d is approximately equal to $I_d\,[R_d(v)]_0$ over the current range shown in Fig. 2. For diodes of this type, in which the voltage drop across r_d can be neglected, the shape of the curve of I_d/I_p as a function of V_d usually depends very little on I_p and r_d. For diodes in which the voltage drop across r_d is appreciable, the current-voltage curve generally shifts to the right, i.e., voltages corresponding to peak and valley currents are higher than shown in Fig. 2.

Presently available tunnel diodes have values of I_p varying from about one-half milliampere to a few hundred milliamperes. Although the ratio of I_p to I_v (where I_v is the value of current corresponding to V_v) usually exceeds 5:1, ratios of better than 20:1 have been obtained[6,7].

In a-c applications, the quantity of most interest is not the total value of the junction resistance $[R_d(v)]_0$, but rather its a-c value $R_d(v) = dv/dI_d$. For the two diodes of Fig. 2, R_d is negative over a voltage range from 0.05 to 0.27 volt for the germanium unit and 0.09 to 0.42 volt for the gallium-arsenide unit.

The series inductance L_d and the junction capacitance $C_d(v)$ of a tunnel diode can be determined from a-c impedance measurements. Theoretically, the variation of C_d with voltage when V_d is less than V_v may be approximated by:

$$C\,(v) \approx K\,(\phi - v)^{-1/2} \qquad (2)$$

Where, K and ϕ are constants. Fair agreement between experimental values of C_d and the values predicted from equation 2 may be obtained by setting the value of ϕ equal to 0.6 volt for germanium and 1.1 volts for gallium arsenide[6].

In commercially available tunnel diodes, L_d varies from about 4×10^{-10} to 20×10^{-9} henry. Experimental units using a housing similar to one described by Hilibrand et al[8] have a value of L_d of about 3×10^{-10} henry. The C_d in commercially available diodes (C_d is usually measured at V_v) varies from 4×10^{-12} farads to 300×10^{-12} farads. Experimental diodes may have capacitances from about 0.4×10^{-12} to 500×10^{-12} farads.

IMPEDANCE OF TUNNEL DIODES

In terms of the incremental resistance R_d, the small-signal a-c impedance Z_d of a tunnel diode may be written as follows:

$$Z_d = \left(r_d - \frac{|R_d|}{R_d{}^2 C_d{}^2 \omega^2 + 1} \right) + j\left(\omega L_d - \frac{R_d{}^2 C_d\,\omega}{R_d{}^2 C_d{}^2 \omega^2 + 1} \right) \qquad (3)$$

Where, it is assumed that the diode is biased in a region where R_d is negative. (Unless otherwise noted, it will be assumed throughout that R_d is negative.) In order that the diode exhibit negative resistance, $|R_d|$ must be greater than r_d. The real part of the impedance, $Re(Z_d)$, is equal to $(r_d - |R_d|)$ at zero frequency and increases monotonically with frequency. The frequency at which $Re(Z_d)$ becomes zero is called the cutoff frequency f_c, and is given by:

$$f_c = \frac{\sqrt{|R_d|/r_d - 1}}{2\pi\,|R_d|C_d} \qquad (4)$$

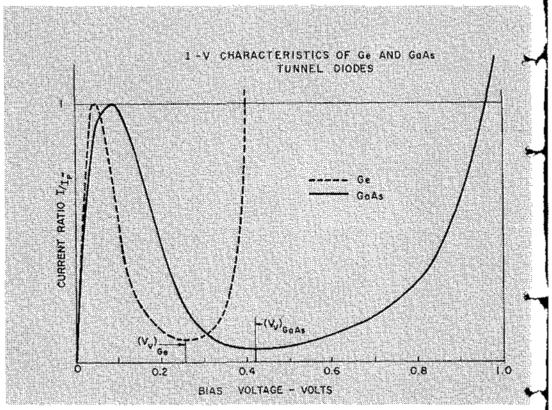


Fig. 2—Current-voltage characteristics of typical germanium and gallium-arsenide tunnel diodes.

At frequencies above f_c, the value of $Re(Z_d)$ is positive.

The imaginary part of the impedance, $Im(Z_d)$, becomes zero at frequency f_r, where

$$f_r = \frac{\sqrt{R_d{}^2 C_d/L_d - 1}}{2\pi\,|R_d|\,C_d} = \frac{1}{2\pi}\sqrt{\frac{1}{L_d C_d} - \frac{1}{R_d{}^2 C_d{}^2}} \qquad (5)$$

Usually, f_r is referred to as the self-resonant frequency of the diode. Below self-resonance, the reactance of the diode is capacitive; above self-resonance, it is inductive.

The maximum values of f_c, of $1/|R_d|\,C_d$, and of f_r for commercially available tunnel diodes are about 5 kMc, 1.5 ×

10^{10} per second, and 2 kMc, respectively. For experimental units the maximum values obtained at RCA Laboratories are about 40 kMc, 2 × 10^{11}/second and 8 kMc.

OSCILLATORS USING LUMPED-CIRCUIT PARAMETERS

From an analytical standpoint, the simplest possible tunnel-diode oscillator circuit consists of a diode shunted by the series combination of an inductance L_c, a series resistance r_c, and a d-c voltage source V_b, as shown in Fig. 3a. This circuit, for operation below the self-resonant frequency of the diode, is useful in many practical applications and is analyzed in some detail below.

Above self-resonance, the reactance of the diode is inductive. Therefore, to obtain oscillations at frequencies above the self-resonance frequency it is necessary to use a circuit which presents a capacitive reactance at the oscillation frequency. Experimental oscillators built at RCA have produced almost perfect sinusoidal oscillations well above the self-resonant frequency of the diode.

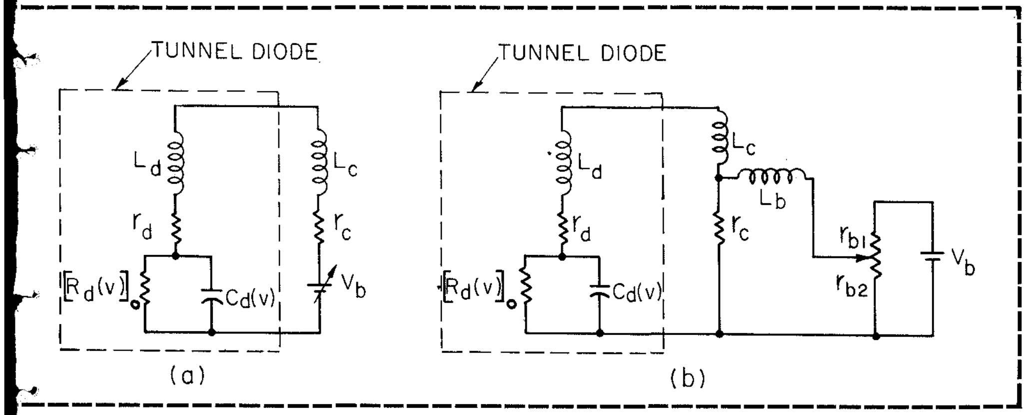


Fig. 3—Tunnel-diode oscillator circuits for operation below the maximum self-resonance frequency of the diode.

In many tunnel-diode oscillators, the inductance of the leads from the d-c power supply to the oscillator is much greater than the desired value of L_c. The problem of lead inductance can be obviated through use of the circuit shown in Fig. 3b. In this circuit, the resistor r_c can be placed close to the diode and the inductance of the bias leads L_b does not affect the performance of the circuit, provided both r_{b1} and r_{b2} are much larger than r_c.

If it is assumed that the value of $C_d(v)$ is given by equation 2, the application of Kirchhoff's laws to the circuit of Fig. 3a leads to the following simultaneous equations:

$$f(v) + \frac{Kdv}{dt}(\phi - v)^{-1/2}\left[1 + v/2(\phi - v)\right] - I = 0 \approx f(v) + \frac{Kdv}{dt}(\phi - v)^{-1/2} + I \qquad (6)$$

$$Ir + L\frac{dI}{dt} + v = V_b \qquad (7)$$

Where, v = voltage across R_d and C_d, and $f(v) = v/[R_d(v)]$, $r = r_d + r_c$, $L = L_d + L_c$, and I = current through L and r.

Equations 6 and 7 are nonlinear differential equations which cannot be solved in closed form. Therefore, some of the general properties of the solutions to these equations are first obtained by a small-signal analysis.

The initial response of the network to a small-signal excitation can be determined by taking the Laplace transform of equations 6 and 7. Initial conditions for equations 6 and 7 are chosen to make R_d negative at time $t = O$. The resultant characteristic equation is given by:

$$s^2 LC_{di} + s(rC_{di} - L/|R_{di}|) + (1 - r/|R_{di}|) = 0 \qquad (8)$$

Where, R_{di} and C_{di} are the initial values of R_d and C_d, respectively.

Equation 8 can be solved for s, the familiar generalized frequency, as follows:

$$s_{1,2} = \sigma_i \pm j\omega_i$$

$$s_{1,2} = -\frac{1}{2}\left(\frac{r}{L} - \frac{1}{C_{di}|R_{di}|}\right) \pm \left[\frac{1}{4}\left(\frac{r}{L} - \frac{1}{C_{di}|R_{di}|}\right)^2 - \frac{1 - r/|R_{di}|}{LC_{di}}\right]^{1/2} \qquad (9)$$

A growing solution is obtained if $\sigma_i > 0$. This condition for σ_i is satisfied if either one or both of the following inequalities hold:

$$L > r|R_{di}|C_{di} \qquad (10)$$

$$r > |R_{di}| \qquad (11)$$

The initial growth can be either purely exponential ($\omega_i = 0$) or sinusoidal ($\omega_i \neq 0$). The conditions for sinusoidal growth are inequality 10 and

$$\frac{1}{LC_{di}} > \frac{1}{4}\left(\frac{r}{L} + \frac{1}{C_{di}|R_{di}|}\right)^2 \qquad (12)$$

The initial frequency of oscillation ω_i is given by the second term of equation 9. The steady-state frequency ω_s differs, however, from ω_i because of the nonlinearities of the diode. Also, although the oscillations grow initially at the rate $\exp(\sigma_i t)$, there can be, of course, no net growth in the steady state. This difference between initial and steady-state behavior of the oscillator can be accounted for by the assumption that both ω and σ are functions of time:

$$\left[\lim_{t \to \infty} \sigma(t) < 0\right]$$

$$\omega(o) = \omega_i, \lim_{t \to \infty} \omega(t) = \omega_s \qquad (13)$$

$$\sigma(o) = \sigma_i, \lim_{t \to \infty} \sigma(t) = 0 \qquad (14)$$

(If inequality 11 holds, there exists the possibility of a nonoscillating steady state.) For the steady state, equations 9, 13, and 14 yield:

$$L = r|R_{de}|C_{de} \qquad (15)$$

$$\omega_s = \left(\frac{1 - r/|R_{de}|}{LC_{de}}\right)^{1/2} \qquad (16)$$

Where, R_{de} and C_{de} are the effective steady-state values of the a-c junction resistance and the junction capacitance, respectively. Accurate values of R_{de} and C_{de} can be obtained only by use of lengthy numerical or graphical methods. However, if only moderate variations in R_d and C_d are encountered, then, to a first approximation, R_{de} and C_{de} can be replaced by their average values $\overline{R}_d$ and $\overline{C}_d$, and equations 15 and 16 become:

$$L \approx r|\overline{R}_d|\overline{C}_d \qquad (17)$$

$$\omega_s \approx \left(\frac{1 - r/|\overline{R}_d|}{L\overline{C}_d}\right)^{1/2} \qquad (18)$$

Substitution of $r = L/\overline{C}_d|\overline{R}_d|$ and $L = L_d + L_c$ in equation 18 results in:

$$\omega_s \approx \left[\frac{1}{(L_d + L_c)C_d} - \frac{1}{\overline{R}_d^2\,\overline{C}_d^2}\right]^{1/2} \qquad (19)$$

Comparison of equation 19 with equation 5, the equation for the self-resonance frequency f_r, shows that in practical circuits ω_s is less than or equal to ω_r, i.e., the circuits of Fig. 3 cannot pro-

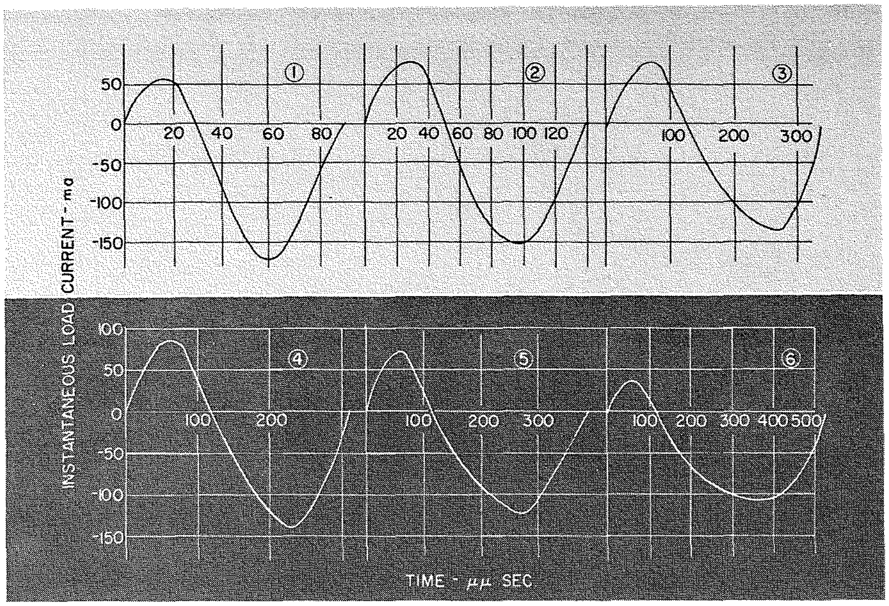


Fig. 4—Calculated steady state wave shapes of tunnel diode oscillators.

duce oscillations above the maximum self-resonance frequency of the diode.

The rf power, P, delivered by a linear negative resistance is

$$P = V_r I_r \qquad (20)$$

Where, V_r and I_r are the rms values of voltage across and current through the negative resistance respectively. To a first approximation, a tunnel diode can be considered to be a linear negative resistance in the voltage range from V_p to V_v; the power delivered by the diode (assuming $r_d = 0$) for an rf voltage swing in this range is:

$$P \approx \frac{1}{8} (V_v - V_p)\ (I_p - I_v) \qquad (21)$$

A better approximation to the I-V characteristics of the diode can be obtained, in analogy with the classical theory of vacuum tube oscillators, by writing the current as a third-degree polynomial of the voltage.[11]

Complete solutions, including power output, harmonic content, and frequency, of equations 6 and 7 can be obtained to any desired degree of accuracy by use of numerical calculus. The required calculations using the approximate form of equation 6 were programmed for an automatic digital computer. The program used a subroutine (written by Dr. F. Edelman of the RCA Laboratories) for the solution of systems of first-order ordinary differential equations. The subroutine is based on methods originated by Milne[9] and Runge-Kutta-Gill[10]. The tunnel-diode current I_d was approximated by the following expression (developed by Dr. R. Klopfenstein and A. H. Simon of the RCA Laboratories) in which $A_1, A_2 \ldots A_6$ are constants:

$$I_d = A_1 V_d + A_2 V_d^2 + A_3 V_d \exp\left(-\tfrac{2}{3}\right) \left(\frac{V_d}{A_4}\right)^{3/2} + A_5 \left[\exp(A_6 V_d) - 1\right] \qquad (22)$$

An excellent fit of each of the tunnel-diode characteristics shown in Fig. 2 was obtained by proper choice of the six constants. Table I summarizes some of the results obtained on the computer. Fig. 4 shows the computed steady-state wave shapes.

The following qualitative conclusions can be drawn from Table I:

The voltage swing across the diode junction increases as L is increased if all other diode and circuit parameters are held constant (see cases 1, 2, and 3). This fact can be explained as follows: in the steady state, $r\,|R_{de}|\,C_{de}/L = 1$ (Equation 15). As L is increased, $|R_{de}|\,C_{de}$ must increase proportionally, i.e., the voltage swing across the diode must increase.

Although the voltage swing across the diode junction increases as L increases (cases 1, 2, 3), the rf power delivered to the load decreases, primarily because the voltage drop across L increases.

Cases 1, 2, and 3 show that, for a diode biased in the center of the negative-resistance region, the harmonic power output increases as the voltage swing across the diode increases. This result is to be expected because the V-I characteristic of the diode is more nonlinear for large voltage swings.

The maximum power output of a tunnel-diode oscillator usually occurs at a bias somewhere between the maximum negative-resistance point and V_v. Cases 3 to 6 illustrate the increase in power with increasing bias voltage at voltages below the bias voltage corresponding to maximum power output. These cases also show that the frequency decreases with bias voltage in this voltage range.

Finally, the table also indicates that equation 19, with $\overline{R}_d = R_{dt}$, and $\overline{C}_d = C_{dt}$, represents at least a fair approximation of the steady-state solution for the frequency in equations 6 and 7, as long as the diode is biased near the center of the negative resistance region.

Figs. 5a to 5h are oscilloscope tracings of the output of a germanium tunnel-diode oscillator of the type shown in Fig. 3b as a function of bias across the diode. As predicted by the analytical solutions of equations 6 and 7, the oscillations are nearly sinusoidal if the diode is biased in the middle of the negative-resistance region. The experimental wave shapes and the variation in frequency with bias agree well with those calculated. It is

TABLE I — RESULTS OF SOLUTIONS OF EQUATIONS 6 (APPROXIMATE FORM) AND 7 OBTAINED ON THE DIGITAL COMPUTER. The current-voltage characteristics of a germanium tunnel diode having a peak current of 10 ma were used in the calculations. Other parameters were: $K = 1.4 \times 10^{-12}$ volts$^{1/2}$ farad, $\phi = 0.58$ volt, $r = 2.5$ ohms.

					Calculated Values					
Case	V	L	$\frac{r\,\vert R_{dt}\vert\,C_{dt}}{L}$	$\frac{1}{2\pi}\left(\frac{1-r/\vert R_{dt}\vert}{LC_{dt}}\right)^{1/2}$	$V_{\min}$	$V_{\max}$	f_s	r f power to load r*, mw Harmonic		
	volts	henrys		Mc	volts	volts	Mc	1	2	3
1	0.13	8×10^{-11}	0.58	10540	0.040	0.187	11370	0.296	9.8×10^{-4}	1.4×10^{-3}
2	0.13	2×10^{-10}	0.23	6670	0.005	0.233	7140	0.185	7.9×10^{-4}	4.9×10^{-5}
3	0.13	8×10^{-10}	0.058	3330	−0.012	0.312	3030	0.124	3.7×10^{-2}	1.2×10^{-4}
4	0.156	8×10^{-10}	0.14	3613	−0.01	0.349	3252	0.139	1.9×10^{-3}	2.9×10^{-6}
5	0.11	8×10^{-10}	0.067	3480	−0.009	0.256	2604	0.116	3.5×10^{-3}	1.1×10^{-4}
6	0.085	8×10^{-10}	0.083	3640	−0.003	0.189	1865	0.063	5.0×10^{-3}	4.5×10^{-4}

* The approximation $P = \frac{1}{8}(V_v - V_p)\,(I_p - I_v)$ yields a value of 0.25 mw for the power delivered to r.

TABLE II — CHARACTERISTICS OF EXPERIMENTAL TUNNEL-DIODE OSCILLATORS

Type of Circuit	Diode Peak Current, ma	Diode Material	No. of Diodes	Oscillation Frequency, Mc	Maximum Power Output, mw	Tuning Range, Mc	$\frac{1}{8}(I_p\text{-}I_v)(V_v\text{-}V_p)$ mw
Straight strip cavity	210	Ga-As	1	610	10	——	8.6
Straight strip cavity	53	Ga-As	1	900	1.7	——	2.4
Straight strip cavity	50	Ga-As	2	950	3	——	4.8
Re-entrant strip cavity	210	Ga-As	1	1600	2	——	8.6
Ridge-waveguide cavity	37	Ge	1	2800	0.7	2700–2900	1.3
Ridge-waveguide cavity	37	Ge	1	5500	0.2	5400–5600	1.3
Strip-line re-entrant cavity	13.7	Ge	1	7130	0.012	——	0.5
Strip waveguide	13.7	Ge	1	8350	——	——	0.5

interesting to note that this oscillator can produce almost undistorted sine waves, even though the ratio $(r\,|R_{dt}|\,C_{dt})/L$ is about 0.006 and inequality 12 is not satisfied. Thus the initial growth must be purely exponential, i.e., nonperiodic.

OSCILLATORS USING DISTRIBUTED CIRCUITS

In tunnel-diode oscillators operating above a few hundred megacycles, it is convenient to use transmission-line resonators. Suitable resonators can be built from coaxial lines, strip transmission lines, waveguides, and the like. The mathematical description of an oscillator using this type of resonator generally involves nonlinear partial differential equations, for which complete solutions are very difficult to obtain. The solutions of these equations are somewhat simplified if it is valid to assume that the oscillator circuit consists of lumped elements connected by uniform transmission lines. This assumption is valid for many practical microwave oscillators. Tunnel diodes can be packaged in housings that are sufficiently small to be considered lumped circuit elements up to frequencies well above 10,000 Mc. It is also possible to build stabilizing resistors that can be treated as lumped circuit elements up to these frequencies.

The characteristic equations of circuits consisting of lumped elements connected by transmission lines can be found in the conventional manner by using the generalized frequency $s = \sigma + j\omega$ in the expression for either the impedance or admittance of the circuit. In general, the characteristic equation will be transcendental, and will have an infinite number of eigen-frequencies $s_n = \sigma_n + j\omega_n$. If σ_n is greater than zero, then oscillations can occur at frequency ω_n. However, if there exists no σ_n greater than zero, the circuit will be stable. Unlike the two cases of lumped circuits discussed previously, in the distributed case it is very difficult to express the condition for the start of oscillation in closed form. It is possible, however, to determine the stability of a particular circuit by solving its characteristic equation by either numerical or graphical means.

For steady-state oscillations the effective value of the impedance or admittance at any point in the circuit must be zero. For small-amplitude oscillations the effective values are nearly equal to the initial values, and an approximation of the steady-state frequency of oscillation can be calculated. In Fig. 6 the conductance and susceptance of a tunnel diode are plotted as functions of frequency. The stabilizing resistors in a number of oscillator circuits using this diode were adjusted to a value at which oscillations were just maintained. The conductance and susceptance of the circuits were calculated and their negative values plotted in Fig. 6 for comparison with the diode curve. It can be seen that the sum of the initial admittance of the diode and the admittance of the circuit is indeed nearly zero.

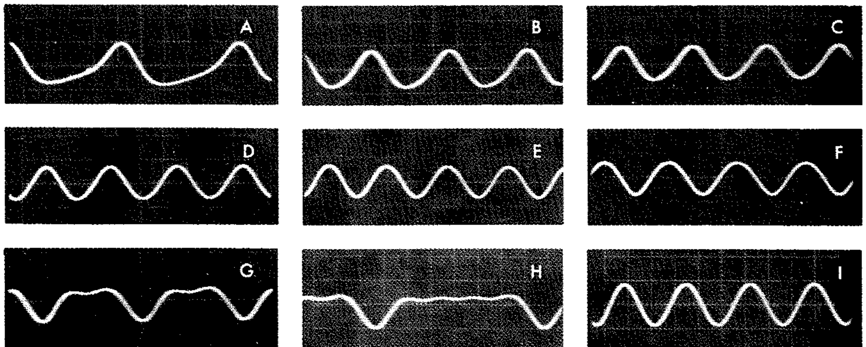
For oscillations with appreciable amplitude, the effective average value of R_d is several times as large as the minimum value. Therefore, in the design of circuits for oscillators with appreciable power output, it is helpful to plot the impedance or admittance of the tunnel diode as a function of frequency for a value of R_d several times the minimum value. This curve differs, in general, by only a relatively small amount from that for a minimum R_d except in the neighborhood of self-resonance, where the difference may be very large. Thus at frequencies removed from f_r, the exact choice of $\overline{R}_d$ is not critical.

Figs. 7 and 8 show tunnel-diode oscillator circuits which use straight and re-entrant strip transmission-line resonators, respectively. These circuits have also proven to be useful in amplifier applications.

The frequency of oscillation of the circuits of Figs. 7 and 8 can be electrically varied by insertion of a variable capacitor in regions of high electric field. The circuit of Fig. 7 can also be mechanically tuned by varying l_2. R. Steinhoff of the RCA Electron Tube Division has designed a 1000-to-1500-Mc mechanically tunable oscillator, of the type shown in Fig. 7, suitable for commercial production.

Fig. 9 is a photograph of some straight and re-entrant strip transmission-line and waveguide oscillators. The experimental results obtained with these oscillators are listed in Table II. The power outputs obtained are an order of magnitude greater than those previously reported in the literature.[4,5] At the lower frequencies, the power output from these oscillators approaches and in one case even exceeds, $\frac{1}{8}(I_p\text{-}I_v)(V_v\text{-}V_p)$. At the higher frequencies where the effects of series resistance, series inductance, and circuit losses are appreciable, the power output is considerably lower.

Fig. 5—Figures 5(a) to 5(h) are oscilloscope tracings of the output of a germanium tunnel diode oscillator of the type shown in Fig. 3(b) as a function of bias across the diode. Fig. 5(i) is a calibrating 17.9-Mc sine wave with 0.025-volt-rms amplitude. The parameters of the oscillator were as follows: $R_d = 4.3$ ohms, C_d (measured at 0.35 volt) $= 75 \times 10^{-12}$ farad, $r_d = 0.3$ ohm, $L_d = 2. \times 10^{10}$ henry, $L_c = 1.8 \times 10^{-7}$ henry, $r = 3.33$ ohms. The bias voltage across the diode was varied as follows: (a) 0.093 volt; (b) 0.13 volt; (c) 0.15 volt; (d) 0.175 volt; (e) 0.25 volt; (f) 0.28 volt; (g) 0.295 volt; (h) 0.305 volt.



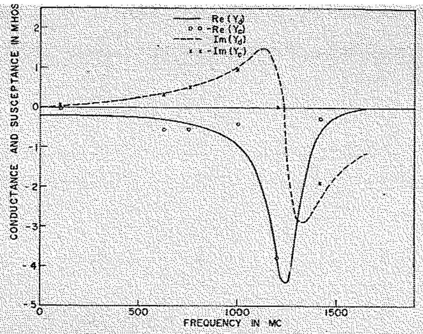


Fig. 6—Conductance and susceptance as a function of frequency for a tunnel diode and its oscillator circuits.

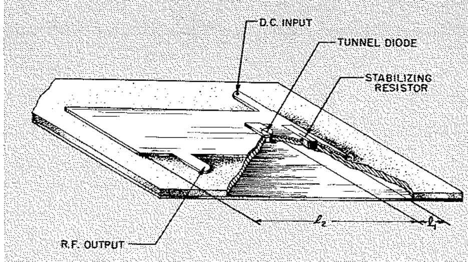


Fig. 7—Tunnel-diode oscillator using a straight strip transmission-line cavity.

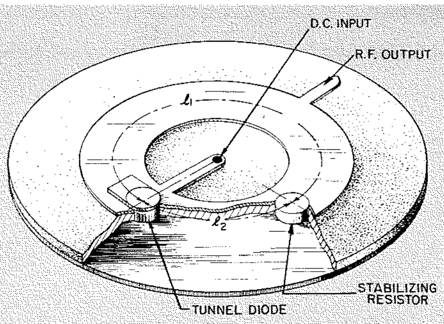


Fig. 8—Tunnel-diode oscillator using a re-entrant strip transmission-line cavity.

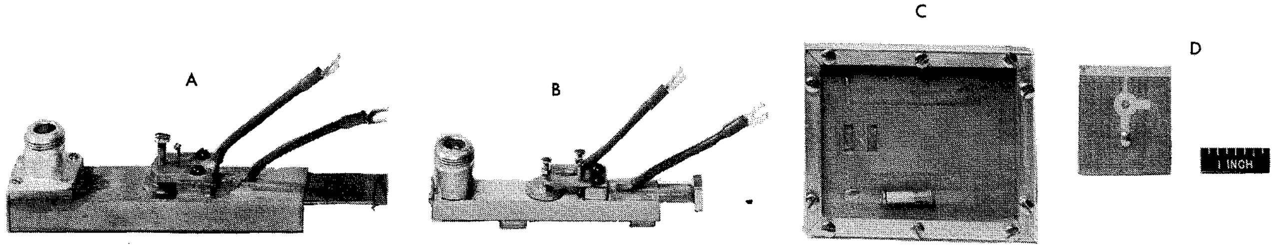


Fig. 9—Tunnel-diode oscillators: A) waveguide resonator, 2600-2800 Mc, 0.67 mw; B) waveguide resonator, 5400-5600 Mc, 0.2 mw; C) re-entrant resonator, 7130 Mc, 0.012 mw; D) straight-line transmission-line resonator, 900 Mc, 3.0 mw.

There is little doubt that power outputs an order of magnitude higher than those listed in Table II can be obtained in the near future. An obvious method of increasing power output is to use multiple-diode oscillator circuits. Another approach is to design tunnel diodes with special junction geometries having low series resistance and inductance, and thus permit the use of higher-current diodes.

CONCLUSION

Experimental oscillators described in this paper have produced power outputs of 10 mw at 610 Mc, 2.0 mw at 1600 Mc, 0.67 mw at 2800 Mc, 0.2 mw at 5500 Mc, and 0.01 mw at 7100 Mc. It is anticipated that considerably higher power outputs will be obtained in the near future. Tunnel-diode oscillators are compact and rugged, are relatively insensitive to nuclear radiation, have very modest power-supply requirements, and can be easily tuned by either mechanical or electrical means; thus, they have significant advantages over low-power vacuum-tube oscillators.

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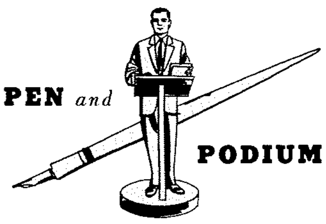
DONALD E. NELSON received the B.S. degree in Electrical Engineering from the University of Illinois in 1941 and the M.S. degree in 1948. From 1941 to 1945 he was employed as a development engineer at Westinghouse Electric Corporation, where he worked on pulsed magnetrons, series spark gaps, TR boxes, and beacon cavities. From 1945 to 1949 he was Research Assistant and Research Associate at the University of Illinois Tube Laboratory, where he worked on cw magnetrons and millimeter-wave devices. He joined the RCA Electron Tube Division in September 1949 as a development engineer, and has since designed a variety of pulse and cw magnetrons. From 1954 to 1958 he was Engineering Leader having technical supervisory direction of all magnetron development in Microwave Tube Engineering at Harrison, N.J. From 1958 to 1959 he worked as a system engineer on the development of microwave tubes for advanced defense systems. In September of 1959 he joined the Microwave Tube Advanced Development activity in Princeton, where he has worked on development of oscillators and amplifiers employing tunnel diodes. Mr. Nelson is a member of Tau Beta Pi, Eta Kappa Nu, and the Institute of Radio Engineers.

DR. FRED STERZER received the B.S. in physics in 1951 from the College of the City of New York, and the M.S. and Ph.D. degrees in 1952 and 1955, respectively, from New York University. From 1952 to 1953 he was employed by the Allied Control Corporation in New York. During 1953 and 1954 he was an instructor in physics at the Newark College of Engineering in New Jersey, and a research assistant at New York University. He joined the RCA Electron Tube Division in Harrison, N.J., in October, 1954, and moved with the Microwave Tube Advanced Development activity to Princeton, N.J., in 1956. He is presently group leader in microwave physics. Dr. Sterzer's work has been in the field of microwave spectroscopy, traveling-wave tubes, backward-wave oscillators, microwave computing circuits, and solid-state microwave devices.



PEN and PODIUM

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DEFENSE ELECTRONIC PRODUCTS

Synchronous Vs. Low-Level Distributed Satellite Communication Systems
H. R. Mathwich: AIEE Meeting, New York, February 1, 1961

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A Practical Parametric Amplifier Design and Its Application to Monopulse Radar
J. A. Luksch, G. A. VerWys: Thesis for Masters Degree, University of Pennsylvania, January 5, 1960

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P. G. Herold: Industrial Management Club, Lancaster, Pa., February 17, 1961

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F. Sterzer, A. Presser, A. H. Solomon: Solid-State Circuits Conference, Pittsburgh, Pa., February 17, 1961

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R. D. Lohman, K. R. DeRemer: AGET Conference on Reliability of Semiconductor Devices, New York City, January 1961

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R. Glicksman: *Journal of Electrochemical Society*, January 1961

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W. A. Pond, M. D. Berkowitz: Electrical-Electronic Procurement Conference, Chicago, January 18, 1961

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R. H. Regimbal: Thesis, University of Pennsylvania, Moore School of EE

Priority Assignment in Control Computers
R. W. Sonnenfeldt, S. B. Dinman: *Control Engineering*, March 1961

Magnetic Memories in Automatic Frequency and Automatic Phase-Control Systems
M. Cooperman: *Electronic Industries*, February 1961

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Predicting Reliability of Electro-Mechanical Devices
I. Kirkpatrick: Sixth National Symposium on Reliability and Quality Control in Electronics, Washington, D. C., Jan. 11-13, 1960

Plasma Physics
Dr. M. P. Bachynski: Ottawa Section IRE, December 2, 1960

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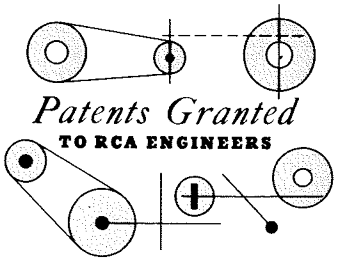
An Improved Loudness Meter
J. L. Hathaway: IRE International Convention, New York, March 21, 1961



Patents Granted TO RCA ENGINEERS

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Noise Reduction System
2,972,018—February 14, 1961; M. E. Hawley and E. D. Simshauser

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2,971,162—February 7, 1961; J. J. Ayres and R. W. Allen

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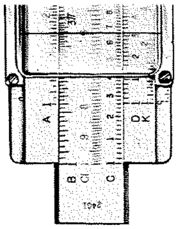
Engineering  NEWS *and* HIGHLIGHTS

ANNUAL SC&M "ENGINEERING ACHIEVEMENT" AWARDS

The Semiconductor and Materials Division has named five of its engineers as recipients of their second annual *Engineering Achievement* awards, which are presented each year during National Engineer's Week. Candidates for the awards are nominated by their managers, on the basis of technical innovation, process improvement, cost reduction, customer acceptance, quality assurance, and "bottleneck breaking." All engineers in the Division are eligible if engaged in a technical phase of the Division's business during at least nine months of that year in a nonsupervisory capacity.

This year's winners are (see photo):

R. F. DeMair, an equipment development engineer at Somerville; he is a graduate of the Polytechnic Institute of Brooklyn, and joined RCA in 1958.

J. S. Horvath, a field engineer in the Los Angeles District Office; he is a graduate of the New York Technical Institute and the RCA Institutes and joined RCA in 1950.

M. F. LaMorte, an Engineering Leader at Somerville; he is a graduate of the Polytechnic Institute of Brooklyn and joined RCA in 1959.

J. M. S. Nielson, a Product Design Engineer at Mountaintop, Pa.; he is a graduate of Albright College and joined RCA in 1958.

R. L. Wilson, an Engineering Leader at Somerville. He is a graduate of the University of Delaware and joined RCA in 1959. —*H. Tipton.*

L. to R.: J. Nielson, R. Wilson, E. O. Johnson (Chief Engineer, SCM Div.), Dr. J. Hillier, Vice President, RCA Labs, M. LaMorte, and R. DeMair. (Not available for pic, J. Horvath, Los Angeles.)

KATZ HONORED FOR PGEM PAPER

In DEP Advanced Military Systems, Princeton, N. J., **A. Katz** recently received Third Honorable Mention and a cash award of $50 for his paper, "An Industrial Dynamic Approach to the Management of Research and Development." The award was from the IRE Professional Group on Engineering Management for papers published in the *PGEM Transactions* from June 1959 to June 1960. —*F. W. Whitmore.*

NEW WEST COAST MICROWAVE LAB

The Electron Tube Division's Microwave Tube Operations opened a new Microwave Engineering Laboratory at 6801 East Washington Blvd., Los Angeles, Calif., in late February. This lab will operate in conjunction with the other Microwave Tube Operations facilities at Harrison and Princeton.

The new lab is under the direction of **C. L. Cuccia,** an authority on magnetrons, traveling-wave tubes, and parametric amplifiers (and a regular RCA ENGINEER author). **C. C. Simeral,** Mgr., Microwave Tube Operations, stated that special requirements for traveling-wave tubes, magnetrons, and pencil tubes would be handled by applications engineers at the lab; in addition, development work and sampling production quantities of solid-state microwave components combining packaged semiconductor diodes and microwave circuitry will be carried out.

DEGREES GRANTED

A. M. Berg, BMEWS Project Engineering, West Coast Missile and Surface Radar Division, Van Nuys, Calif., received his MS in Electrical Engineering from the University of California at Los Angeles.—*D. J. Oda.*

DAVIDSON HONORED FOR BEST ARTICLE

J. J. Davidson, an engineer in the Electrical Design Group, Record Engineering Laboratory, RCA Victor Record Division, Indianapolis, has been honored with a gold medal and $500 for the best technical article published in *Semiconductor Products* between April 1959 and March 1960. The contest, restricted to semiconductor circuit-design papers, was won with "Transistor AC Amplifier with High Input Impedance," which was published in the March 1960 issue.—*M. L. Whitehurst.*

INCREASED EMPHASIS ON TWT

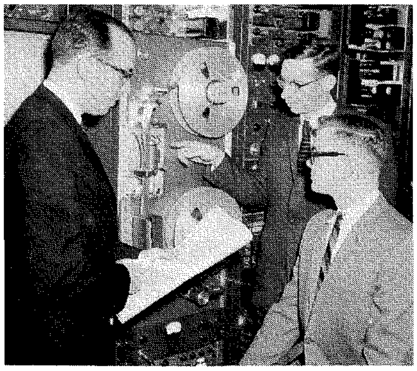
Because of increased interest in traveling-wave tubes for use in microwave communications repeaters, a separate group of engineers has been formed in Electron Tube Division Microwave Engineering whose sole responsibility is development of such amplifier tubes.

G. Novak, Design and Development Activity, is responsible for the technical programs of the group. An example is development of a tube to serve as a satellite-borne microwave amplifier.—*H. J. Wolkstein.*

MARCH, APRIL "IEP ENGINEERS OF THE MONTH"

In IEP, **A. C. Luther, R. N. Hurst,** and **J. R. West** (see photo) have been named *Engineers of the Month* for March. All are with the Broadcast and TV Equipment Division. These men received the award for their excellence of performance in development of the precision line-lock head-wheel servo for the RCA TV Tape Recorder. (See cover and article, this issue.) This new servo reduces machine timing errors by a factor of 100, an outstanding achievement indicative of their individual and collective professional skills. Mr. Luther is Mgr., Advanced Development, Electronic Recording Products Dept.

J. B. Howe, Data Communications and Custom Projects Dept., EDP Division, has been named IEP *Engineer of the Month* for April (see photo). He was honored for his outstanding contributions to the design of the Communications Data Processor for ComLogNet. Clearly defined design objectives and a well-conceived program for timely completion of the system are largely due to Mr. Howe. Both by his efforts and by his guidance of other engineers on the design team, he displayed a high level of professional skill. Mr. Howe is with the Computer Design Engineering section, **J. E. Palmer,** Mgr.—*S. F. Dierk.*



Above: R. Hurst, A. C. Luther, and J. R. West; below: J. Howe.

NATICK EDP PLANT EXPANDED

To handle increased demands for the RCA 110 Industrial Control Computer (see article by R. W. Sonnenfeldt, Vol. 6, No. 4), the RCA 150 Data Analyzer and Recorder, and the RCA 130 Industrial Information Transmission Link, the Industrial Computer Systems Dept. (**C. M. Lewis,** Mgr.), EDP Division, IEP, has doubled its manufacturing and testing space at the Natick, Mass. plant. Coincident with this expansion, **R. S. Fine** was named to supervise production for the Department; he was formerly Supervisor, Audio and Accoustics, for the Home Instruments Division.

JUNE PGPEP CONFERENCE FEATURES SMITH, MEDARIS IN PHILADELPHIA

At the Fifth Annual Conference (theme: *Mechanical Engineering in Space Age Electronics*) of the IRE Prof. Group on Product Engineering and Production, **T. A. Smith,** Executive Vice President, IEP, and (Lt. Gen.) Medaris, former head of ABMA, will be featured speakers (June 14-15, Sheraton Hotel, Philadelphia).

Four sessions will cover *Research, Data Processing, Packaging,* and *Systems Engineering.* Pertinent products will be exhibited. **W. J. Welsh,** DEP Moorestown, is Registration Chairman and may be contacted for reservations.

TEN RCA MEN AWARDED SARNOFF FELLOWSHIPS FOR GRADUATE STUDY

David Sarnoff Fellowships have been awarded to ten RCA men for graduate studies in Physics, Engineering, Mathematics, and Business Administration for the 1961-62 academic year. The grants, announced by **Dr. Irving Wolff,** Chairman of the RCA Education Committee, are worth up to $6000 each, and include full tuition and fees, an allowance for books, a stipend of $2500 to $4000 depending on marital status, and $1000 as an unrestricted gift to the university. Although the grants are for one year, each Fellow is eligible for reappointment; this year, four of the ten are receiving the fellowships for the second consecutive year.

The four Fellows reappointed for a second year include:

H. Anderson, 28, Electron Tube Division, Harrison, for an MBA in Management at Harvard. He received his BS in Accounting from Bryant College in Providence, R. I., in 1952, and his BS in Mechanical Engineering from Newark College of Engineering in 1960.

A. B. Corderman, 32, DEP Aerospace Communications and Controls Div., Burlington, Mass., for a Ph.D. in Business Administration at Harvard. He attended the U. S. Naval Academy and Rutgers University, and was accepted for the Ph.D. studies even though he does not possess an undergraduate degree.

I. J. Fredman, 28, RCA Service Co., Riverton, N. J., for a Ph.D. in Mathematics at the University of Pennsylvania. He received a BA in Mathematics from Temple University in 1955, and an MA in Mathematics from Temple in 1959.

S. Skalski, 27, RCA Semiconductor and Materials Division, Somerville, for a Ph.D. in Physics at Rutgers University. He received his BS in Physics from the Polytechnic Institute of Brooklyn in 1958.

Those six receiving the Fellowships for the first time are:

J. A. Adolphson, 28, DEP Aerospace Communications and Controls Div., Camden, for MBA in Industrial Management at the Univ. of Pennsylvania. He received his BS in Industrial Management from LaSalle College in 1960, and has been pursuing graduate studies at Temple University.

Nils C. I. Hokansson, 27, IEP Electronic Data Processing Division, Boston, for an MBA in Industrial Management at Boston University. He received his BS in Business Administration from Northeastern University in 1956 and has been pursuing graduate work at Boston University.

J. Y. Robertson, 29, DEP Surface Communications Division, Camden, N. J., for a Ph.D. in Electrical Engineering at the University of California. He received his BS in Electrical Engineering from the University of California in 1957, and an MS in Electrical Engineering from that school in 1959.

W. R. Atkins, 26, RCA Victor Co., Ltd., Montreal, Canada, for a Ph.D. in Engineering at the University of London, London, England. He received his BS in Electronics Engineering from the University of Alberta in 1956, and his MS in Electronics from the University of London in 1959.

K. H. Zaininger, 31, RCA Laboratories, Princeton, N. J., for a Ph.D. in Electrical Engineering at Princeton University. He received his BS in Electrical Engineering from the City College of New York in 1959, and has completed one year of graduate study at Princeton.

S. P. Hofstein, 22, RCA Laboratories, Princeton, N. J., for a Ph.D. at Princeton University. He received his BS in Electrical Engineering from the Cooper Union in 1959, and expects his MS in Electrical Engineering from Princeton in June 1961.

SERVICE CO. OFFERS EVENING EDP COURSES FOR ENGINEERS

Over 100 engineers and local science instructors are now attending a 10-week, specially devised evening course at the EDP Training Center, Cherry Hill, N. J. This comprehensive, sophisticated course presents logic design, programming, problem analysis, and computer applications at a level suitable for professional engineers who have not previously been formally oriented to computers.

An accelerated 7-week version of this course will be offered in July 1961. *Interested engineers should contact the EDP Training Center for details.*

Besides this EDP course for engineers, the Center also offers evening courses in Computer Technology and Programming. These courses are available to all RCA personnel, as well as people from outside RCA.—*J. Lawler.*

NEEDHAM NOW PRODUCING COMPLETE CUSTOM MEMORIES FOR COMPUTERS

The Semiconductor and Materials Division's Needham Materials Operation, Needham, Mass., has increased the size of its manufacturing facilities in order to produce complete computer memory units, as well as memory components. Previously, the Division had supplied components to computer manufacturers for memory fabrication.—*E. I. Small.*

RIPPERE HONORED WITH "LEGION OF MERIT" BY USAF

The USAF awarded the Legion of Merit to **Col. J. B. Rippere** (ret), Staff Engineer. He reports to **J. D. Woodward,** Chief Engineer, Aerospace Communications and Controls Division, DEP, Camden, N. J. Mr. Rippere joined RCA in 1960 following his retirement from the USAF with 24 years of service. He received the citation for . . . *exceptionally meritorious conduct . . . as Chief, Communications and Navigation Laboratory, Wright Air Development Division, WPAFB, Ohio, from June 1956 to July 1960 . . .* [*for*] *outstanding ability in organization of electronic engineering talent . . .*
—*R. D. Crawford.*

SCIENTIFIC TECHNIQUES APPLIED TO PACKING AT CAMDEN FACILITY

Newsworthy are the special services offered in Camden by the RCA Packaging Facility. This group of 35 experts "engineers" packing techniques for all kinds of industrial and military electronics equipment through a continuing program of designing and testing packing techniques. Special machines and instruments are utilized to simulate the potential harsh treatment that delicate equipment may receive during shipping.

ENGINEERS IN NEW POSTS

Dr. E. W. Engstrom, Senior Executive Vice President, has announced the following reassignment of duties for **Dr. D. H. Ewing,** Vice President, Research and Engineering: he will have staff responsibility for technical liaison between domestic and foreign research and engineering staffs; he will have responsibility for the technical programs of the Zurich Laboratory Research Group, Switzerland, and will collaborate with the President and Director of Research of Laboratories RCA, Inc., Tokyo, Japan, on the technical programs of that laboratory. He will be available to **C. M. Odorizzi,** Group Executive Vice President, and to RCA International on technical matters, including counseling and advisory services to RCA licensees abroad and to RCA operations abroad. Dr. Ewing will continue to be responsible for the direction of the Operations Research function and will continue to report to Dr. Engstrom.

Dr. G. H. Brown, Vice President, Engineering, **R. A. Correa,** Vice President, Patents and Licensing, and **Dr. J. Hillier,** Vice President, RCA Laboratories, will now report to Dr. Engstrom.

In the DEP Missile and Surface Radar Division, Moorestown, **S. N. Lev,** Division Vice President and General Manager has named **A. L. Hammerschmidt** as Chief Engineer, Engineering Department. Mr. Hammerschmidt had been with NBC as Vice President, Engineering.

In IEP, **J. J. Graham,** Division Vice President and General Manager, Communications and Controls Division, has named **T. L. Dmochowski** as Mgr., Radiomarine Equipment Dept. Mr. Dmochowski's staff includes **N. L. Barlow,** Mgr., Fixed Communications Engineering and **C. E. Moore,** Mgr., Radar Engineering. Also in that Division, **S. K. Magee,** Mgr., Controls and Scientific Instruments Dept., has named **H. C. Gillespie** as Mgr., Engineering.

In the Tube Division Industrial Tube Products Dept., **C. C. Simeral, Jr.,** Mgr., Microwave Tube Operations names his organization to include: **W. E. Breen,** Mgr., Microwave Manufacturing; **H. L. Eberly,** Mgr., Special Products Manufacturing and Methods Development; and **H. K. Jenny,** Mgr., Microwave Engineering.

NEW "DARK HEATER" IS MAJOR ADVANCE IN RECEIVING TUBES

Two years of research and development have produced a major improvement in receiving tubes through a new chemical material as an insulation coating for the heater wire. The new *dark heater* produces optimum cathode temperature when the heater operates at about 1350 °K, some 20% lower than the 1500 to 1700 °K of the conventional white heater. The new heaters are being used in commercial radio and TV receiving tubes now, with industrial and military types to follow shortly. Improved reliability and performance is a major gain with the new heater.

The dark heater was developed at the Tube Division's Chemical and Physical Laboratory in Harrison, headed by **N. S. Freedman.** Engineers of that laboratory responsible for its development include: **J. J. Carrona, E. Lee, H. G. Scheible,** and **C. W. Horsting.** Important contributions were also made by **W. H. Fonger** and **M. Kestigan** of the RCA Laboratories, Princeton.

PROFESSIONAL ACTIVITIES

RCA Victor Ltd., Montreal: **Dr. M. P. Bachynski** (author, this and last issue), Director of the Microwave Physics Lab, has been named a member of the Advisory Committee on Gas Dynamics by the Canadian Defense Research Board.—*H. J. Russell.*

DEP-ACC, Burlington, Mass.: **Dr. J. J. Bussgang** has been elected Chairman of the Boston Chapter of the IRE Professional Group on Information Theory for 1961.—*R. W. Jevon.*

Record Division, Indianapolis: **H. E. Roys,** Chief Engineer, Record Division, has been elected to serve for a year as Vice Chairman of the IRE Professional Group on Audio. **Dr. A. M. Max** spoke to the Dayton, O. Branch of the American Electroplaters Society on Feb. 15, 1961 on "Factors Which Inflence the Character of ElectroDeposits." **C. Martin,** engineer in the Compound Development Group, spoke on March 21, 1961 to a luncheon Meeting of the Indianapolis Chapter, ACS, on "Miracle Surface Phonograph Records."—*M. L. Whitehurst.*

DEP SurfCom, Camden: **P. J. Riley** has been named General Chairman for the Fifth National Conference of the IRE Professional Group on Product Engineering and Production; for that same Conference, **J. W. Knoll** has been appointed Program Chairman.—*C. W. Fields.*

DEP-M&SR, Moorestown: **H. J. Siegel** (author, Vol. 5, No. 6) has been named to the Special Research Panel on Hull Structural Design of the Society of Naval Architects and Marine Engineers.—*T. G. Greene.*

Semiconductor Division, Somerville: Active at the IRE International Solid State Circuits Conference, Philadelphia, Feb. 15-17, 1961, were: **E. O. Johnson,** Chief Engineer, was Chairman of the "New Device Characteristics" session. He was also Moderator of the "Tunnel Diode" panel; **R. D. Lohman** was a member of the "Micropower Circuit Power" panel; **R. R. Painter** was a "Reliability" panel member.

Tube Division, Harrison: At the IRE International Solid State Circuits Conference, Philadelphia, Feb. 15-17, 1961, **L. Cuccia** was a member of the "Tunnel Diode" panel.

Tube Division, Marion, Ind.: **D. M. Krampe,** Chemical and Physical Lab, is instructing a course in *Basic Mathematics for Electronics* for some 30 technicians at the Marion B&W Kinescope plant. **A. M. Trax,** Mgr., Glass and Metallurgy Group, Chemical and Physical Lab, was guest lecturer at a Glass Symposium held at the New York State College of Ceramics last year; he lectured the over-100 glass technologists present on the tenth anniversary of his graduation from the college.—*J. H. Lipscombe.*

Tube Division, Lancaster: At the AIEE Winter General Meeting, New York, Jan. 29-Feb. 3, 1961, **H. H. Wittenberg** was Chairman of the Electron Tubes Subcommittee; a feature of the meeting were sessions on super power tubes. Several RCA engineers gave papers at this meeting (see *Pen and Podium*).

IEP, Broadcast, Camden: **R. S. Jose** was appointed to the IRE Committee 27.4 on "Spurious Transmitter Radiation"; **T. V. Foley** was named to the EIA Committee TR 21.2 on "Air Dielectric Coaxial Lines and Fittings", replacing **W. N. Moule. D. R. Musson** spoke to the Del. Western Ass'n of Broadcast Engineers in Calgary, Alberta, Canada, on "Theory and Applications of Ampliphase Modulation" on Feb. 22, 1961. —*D. Kentner.*

MAYER NAMED TO NEW RCA INTERNATIONAL ED REP POST; RIPPERE, ANSCHUETZ NAMED ED REPS IN DEP-ACC

C. G. Mayer has been named to fill the newly created post of RCA ENGINEER Editorial Representative for the RCA International Division. He is in charge of Product Planning and Development for the Division. The Editors extend their welcome to Mr. Mayer, whose headquarters are in the Clark, N. J. offices of the Division.

In the DEP Aerospace Communications and Controls Division, **J. B. Rippere** has been named as Editorial Representative, replacing **J. Biewener.** Also in that Division, **E. Anschuetz** has assumed the newly created Ed Rep post for Communications Engineering. (*More on these men in a future issue.*)

C. G. Mayer

C. G. Mayer graduated in Electrical Engineering from the Imperial College of Science and Technology, London, England, and then spent 12 years with the Western Electric Co.

During the past 14 years, he has been RCA European Technical Representative, and negotiated many technical aide and license agreements. He also participated as a U.S. delegation member in nearly all the post-war CCIR Plenary Conferences and Study Group XI (television) meetings, and represented RCA in several other international organizations.

In 1955, while continuing to coordinate licensing activities in Europe, Mr. Mayer pioneered the RCA Laboratories in Zurich, which carry on fundamental research and engineering work for RCA licensees. He was appointed the first President and Managing Director of *Laboratories RCA, Ltd.*, Zurich.

Following this, he was chosen to expand activities of the RCA associate company in England, and became Chairman of the Board and Managing Director of RCA Great Britain, Ltd., with approximately 500 employees. He then became RCA Special Representative in Europe until assuming, in 1959, his present responsibilities.

Mr. Mayer is a licensed Professional Engineer in N.Y., a Sr. Member of the IRE, a *Fellow* of the SMPTE, MIEE, a *Fellow* of the Physical Society and Royal Society of Arts, as well as being a member of several other societies.

TWO NEW DIVISIONS FOR DEP

A. L. Malcarney, Executive Vice President, DEP, has announced creation of two new divisions: the *Aerospace Communications and Controls Division* (ACC), with **I. K. Kessler** as Division Vice President and General Manager, and the *Major Defense Systems Division* (MDS), with **D. B. Holmes** as General Manager.

The ACC Division encompasses the former Airborne Systems Division, Camden, and the Missile Electronics and Controls Division, Burlington, Mass. Mr. Kessler will report to **W. G. Bain,** Vice President and General Manager, Communications and Aerospace. In ACC, **J. D. Woodward** is Chief Engineer, Camden Engineering Dept., and **S. L. Simon** is Chief Engineer, Burlington Engineering Dept.

The MDS Division, Moorestown, will be responsible for managing large systems within the Missile and Surface Radar organization, of which **H. R. Wege** is Vice President and General Manager and to whom Mr. Holmes will report. Mr. Wege's organization will continue to include the separate Moorestown MSR Division and the West Coast (Van Nuys) MSR Division.

SINNETT, KING LECTURE WIDELY ON CREATIVITY AND PROFESSIONALISM

C. M. Sinnett, Director, and **G. W. K. King,** Administrator, Product Engineering Professional Development, have both been very active in lectures and seminars concerned with professionalism and creativity in engineering. Mr. Sinnett participated in one-day IEI seminars in New York, Boston, and Philadelphia on *Locating and Developing Creative Engineers.* He also spoke on "Individual and Group Creativity" at the University of New Hampshire *Conference on Effective Utilization of Engineers,* to RCA engineers in Camden, Marion, and Indianapolis, and to the PSPE of Lancaster, Pa.

Mr. King spoke to GE engineers in Syracuse at a *Professional Creativity* seminar, and made a week-long speaking tour for the IEI in Seattle, San Francisco, Los Angeles, Dallas, and Houston. He also recently led an American Management Assoc. seminar in New York on *Developing Engineering Creativity.*

174 GRADUATED FROM RCA INSTITUTES

At February graduation ceremonies of the RCA Institutes, **C. E. Kapp, W. S. Keith,** and **M. Rosen** shared top honors. The class numbered 174, and included students from Chile, Panama, British West Indies, Spain, Iraq.

ENGINEERING MEETINGS

May 22-24: 5th Global Communications Symposium (GLOBCOM V), IRE (PGCS), AIEE, Sherman Hotel, Chicago, Ill.

May 22-24: National Telemetering Conference, IRE (PGSET), AIEE, IAS, ARS, ISA, Sheraton Towers Hotel, Chicago, Ill.

May 23-25: Symposium on Large-Capacity Memory Techniques for Computing Systems, ONR, Dept. of Interior Auditorium, Washington, D.C.

June 12-13: National Symposium on Radio-Frequency Interference, IRE (PGRFI), Sheraton-Park Hotel, Washington, D.C.

June 14-15: 5th National Conference on Product Engineering and Production, IRE (PGPEP), Sheraton Hotel, Philadelphia, Pa.

June 19-20: 2nd National Conference on Broadcast and Television Receivers, IRE (PGBTR and Chicago Section), O'Hare's Inn, Des Plaines, Ill.

June 26-28: 5th National Convention on Military Electronics, IRE (PGMIL), Shoreham Hotel, Washington, D.C.

June 28-30: Joint Automatic Control Conference, IRE (PGAC), ISA, AIEE, AIChE, ASME, Univ. of Colorado, Boulder, Colo.

Aug. 16-18: Electronic Circuit Packaging Symposium, Boulder, Colo.

Aug. 22-25: Western Electronics Show and Conference (WESCON); IRE (L.A. & S.F. Sections), WCEMA, Cow Palace, San Francisco, Calif.

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