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OUR COVER

As has been our custom over the past nine years in every June-July issue, our cover for this ninth-anniversary issue repeats the basic cover design of the first issue of the RCA ENGINEER (June-July 1955, Vol. 1, No. 1)

Ninth Anniversary

Anniversaries serve as milestones by which we measure our progress, whatever ou field of endeavor. This issue, the ninth anniversary of the RCA ENGINEER, point up the growth and maturity of this publication *"by and for the RCA engineer."*

Communicating to other engineers, to management, to the patent operation, and to the buyer and user of RCA equipment becomes more vital as RCA broadens its technical know-how.

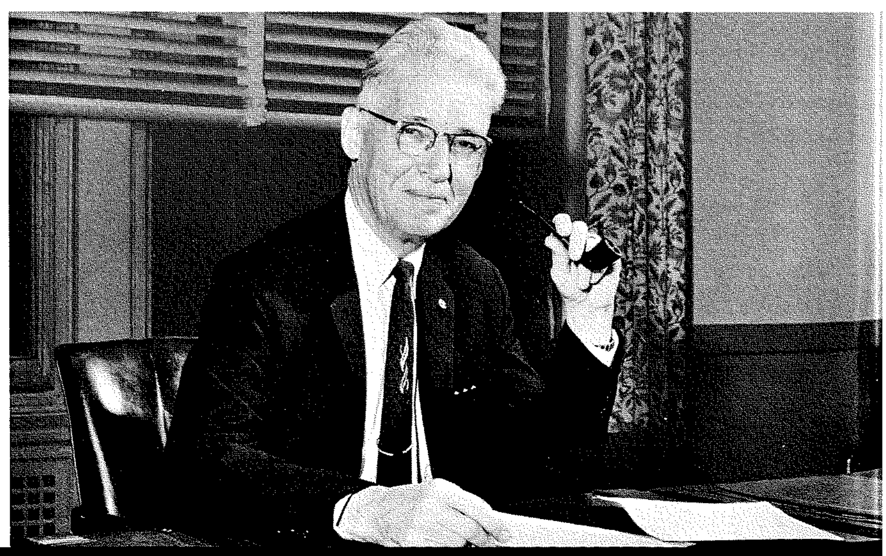
The truly professional engineer knows that a successful development or proto type is only one step on the road to a complete design. He knows also that th value of his achievement may be judged by people who never have an opportunity to see his laboratory model, but learn of it through reading his paper or report So, reporting as well as developing and designing all require a great amount o motivation, creativity, energy, and follow-through.

Writing technical papers and reports, like any other creative effort, has no magi formulas and no short cuts—just a lot of hard work. Occasionally, there may b intuitive flashes which assist, but they occur as infrequently in writing as they do in engineering development and design. For the most part, good papers involve writing, editing, and rewriting until one obtains the desired results. This makes writing sound difficult, and it is—but it is far from impossible for any enginee who would be known as a *professional.* The 54 issues of the RCA ENGINEER published during the past nine years are proof of this. They chronicle RCA's technical advances during a period that has been unequalled in scientific and technical achievements.

A review of the first year's issues of the RCA ENGINEER is enlightening. The problems discussed and the solutions presented differ from today's more in degree than in type. For that matter, some of the same problems are still with us For instance, the first article in Vol. 1, No. 1 is entitled "Why Engineers Shoul Write Papers."

Writing papers is even more important today than it was nine years ago. Th growing diversity of technical knowledge within RCA demands improved com munications if we are to remain competitive. Each engineer and engineering manager should consider it *part of his professional duty and a privilege* to improve these communications through the writing and publication of technica papers and reports.

C. M. Sinnet
Director, Product Engineering Professional Developmen
Radio Corporation of Americ



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DEPARTMENTS

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

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

An index to RCA ENGINEER articles appears annually in the April-May issue.

MANY events can occur that have significant impact on a company's present or future defense business. A government agency may decide to postpone a contract award, thus delaying an anticipated requirement for engineering manpower; or a contract already "in-house" may be converted from cost-plus-fixed-fee to fixed-price, causing a major shift in the time phasing of a company's billing performance; or a major production job may be bid with a corresponding increase in the company's potential needs for direct labor production workers. *Staying abreast of these various changes and assessing their impact on overall company plans is a continuing, complex task.*

In the DEP Communication System Division, a new *BU*siness *P*lanning *A*nd *R*eporting system, BUPAR, has been developed to keep overall plans in tune with these changes; to insure coordination among all functional activities in planning; and to evaluate plans in light of actual performance.

The Engineer and the Corporation

BUPAR

. . . A System Providing Computer-Prepared Business Analyses and Forecasts

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At the heart of the BUPAR System (Fig. 1a) is a master file on an RCA 501 computer. This file contains entries on more than sixty contracts and several hundred potential programs. In each entry, data is included on some thirty types of information, ranging from program status to the projected manpower requirements by month from the date of award through the completion of the contract. An impartial information-gathering activity of three persons gathers the necessary data from marketing, engineering, and production sources, verifying that the information is complete, accurate, and timely. The computer provides bookings, billings, and contract direct-resources forecasts for periods ranging to 5 years in the future, and performs various historical analyses. These forecasts and analyses are essential information for management planning. Fig. 1b shows the flow of BUPAR information in the DEP-CSD organization.

Because BUPAR is a *planning* system, the marketing activity contributes about 70% of the data to the master file. Marketing begins by reporting on new business targets, updating such information periodically with inputs as to the value, proposal status, and probability of a contract award to RCA. Engineering and production activities gauge the contract direct resources needed to perform on each item of business identified by the marketing group. Where the lead time is long, established manpower planning ratios are used. At closer range, data is extracted from proposals or engineering management's monthly estimate of requirements to perform on contracts already in the house. Based upon marketing inputs as to booking date, the type of fee, and proposed contract schedules, a projected billing plan is derived for each program and summarized divisionally.

The forecasts up to 5 years into the future include:

1) Bookings forecast categorized for the company by month, by salesman, and by prime activity.
2) Forecasts of direct contract engineering and production manpower requirements by activity and geographic location.
3) Company billings forecast by month, activity, and type of contract.
4) Special request forecasts sorted by any of the 30 items of information within the master file.
5) Marketing assistance (project analysis funds) forecast by month, by product line, by priority of program.

The historical analyses include:

1) Comparison of actual performance to the above forecasts.
2) Analysis of factors in successful bidding.
3) Proposal follow-up analysis including such factors as total number of solicited and unsolicited proposals submitted, and won-loss average by product line, by customer, by type of fee, etc.
4) Statistical record of each program from its inception to final disposition.

INPUTS TO BUPAR

Fig. 2 illustrates the procedure for updating the information within BUPAR. Marketing has assigned one person to submit all marketing data to the information-gathering group. Such data may be either *dynamic* (changing information such as the probability, value, estimated booking month, and status of potential programs) or *static* (information which, once collected, does not change often, such as type of fee, product line, prime activity, and customer).

At an appointed time within each month the marketing representative contacts the salesmen and contract administrators and has them add, delete, and/or revise the dynamic information on those potential and in-house programs for which they are responsible. One of the BUPAR outputs is a monthly bookings forecast showing in-house and potential contracts categorized according to responsible salesman (if new business) or contract administrator (if add-on effort). For ease of updating, the salesmen and contract administrators merely pencil in any changes on their last month's forecast. Thus, the previous month's booking forecast becomes the updating vehicle for the current month's forecast. The BUPAR marketing representative collects, reviews, and submits the updated forecasts to the information-gathering group. In addition, he gathers the static data from marketing documents and personnel. This division of effort is followed in order that the salesmen and contract administrators not be burdened with excessive administrative detail. Consequently, they are required only to update changing information.

Engineering also assigns one person to submit all engineering data to the information-gathering group. He has two primary functions related to BUPAR; 1) to see that the engineering activity receives by the 10th of each month "draft" engineering contract direct resources forecasts for their activities. This is similar to the previous month's contract direct resources forecast with the exception that it contains the latest marketing estimate as to the probability, value, and status of potential programs, plus any new contracts since the last forecast. This draft or "first-cut" forecast is the updating vehicle used when engineering goes through the monthly full-scale updating between the 13th and 23rd of each month.

Engineering managers and leaders are required only to update those programs they are closest to, namely, in-house contracts. The BUPAR representative takes the engineering estimates of contract direct resources from the text of the

Final manuscript received January 10, 1964.

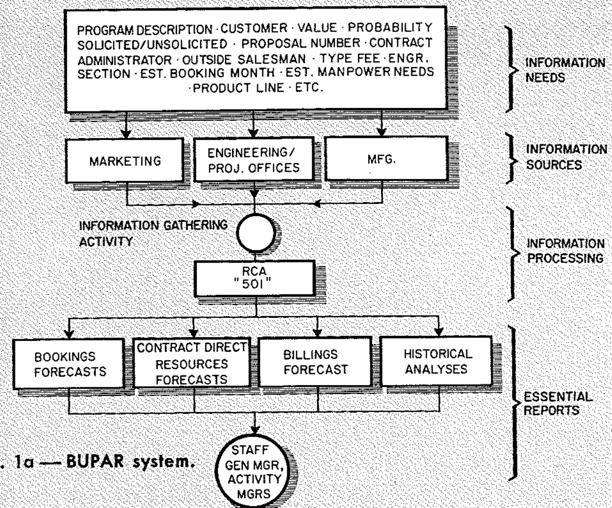

Fig. 1a — BUPAR system.

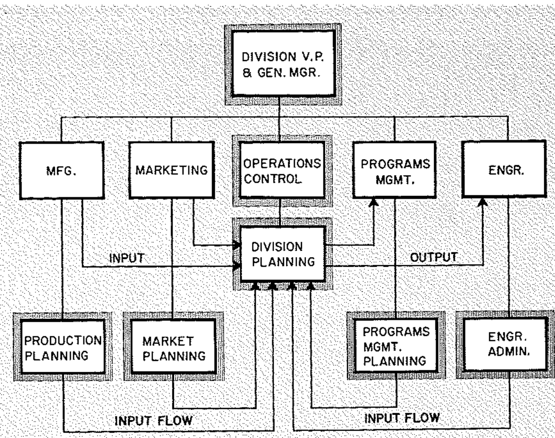

Fig. 1b — BUPAR information flow in CSD.

proposal on anticipated programs. The computer is programmed to calculate and phase out direct contract engineering resources on unproposed potential programs. Prior to the BUPAR system, the engineering activities had to estimate contract direct resources on *both* in-house and anticipated programs. Their job was made more difficult because the latest marketing intelligence on anticipated program was not timely or comprehensive. Production direct contract resources can be forecasted by a procedure similar to that now being followed by engineering. This phase of BUPAR may be implemented in the near future.

The updated marketing, engineering, and production information is punched onto cards, then transferred to magnetic tape for updating the existing master file. All the forecasts and historical analyses previously mentioned are printed from the updated master file and are then distributed to the general manager and staff. Specific forecasts serve as the updating vehicle for the next month's forecasts.

HOW BUPAR IS USED

Marketing and engineering use BUPAR to prepare operating forecasts, assign personnel, and allocate financial resources.

Preparation of Forecasts

Periodically updated BUPAR forecasts, together with actual data, enable management to reassess their plans monthly. Through BUPAR, the marketing activity prepares a monthly forecast of contract awards and a forecast by sales personnel. The forecast of contract awards lists, for each month, all contracts for which DEP-CSD is competing or plans to compete. These contracts are classified as either new business or extensions to existing contracts. The contracts are further classified according to probability of award. By means of this probability, the computer is able to calculate an "expected" or "factored" value of total awards for each of the next 12 months. A summary page, comparing these expected values for each month against the budgeted monthly bookings plan is prepared for review by the general manager, his staff, and others who spend the time reviewing the more detailed information contained in the monthly summaries.

BUPAR prepares for engineering groups a monthly forecast of contract direct resources to support in-house and marketing-identified potential programs—the same ones appearing on the marketing forecast of contract awards. (BUPAR can prepare similar forecasts for production.) Within DEP-CSD, much of the planning is product-line oriented. The engineering skills required to support each product line are identified. The computer recognizes the product line for each job, and then calculates the phases over the life of the program the engineering contract direct resources estimated to support the program. After all potenial programs have been processed, a forecast by each engineering activity can be printed in both detail and summary form. Within

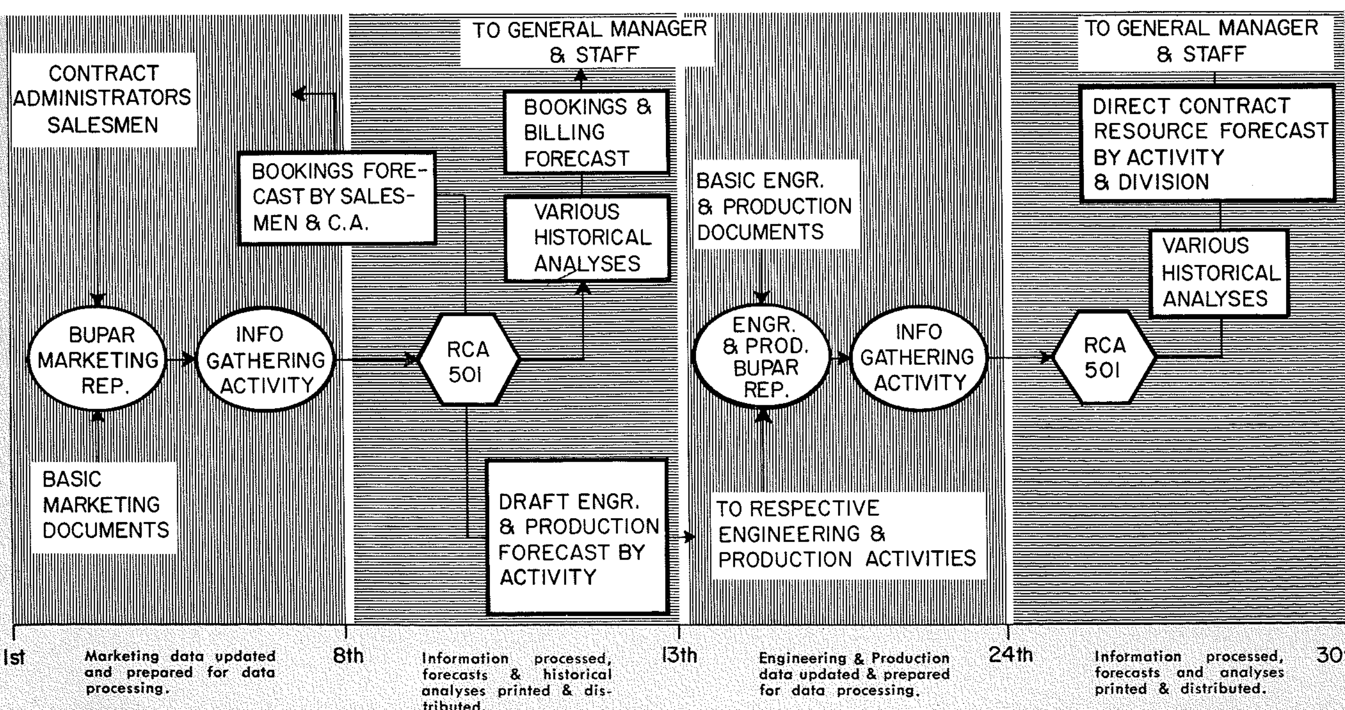

Fig. 2—How BUPAR is updated.

each activity, the programs are classified by nature (e.g., development, or production) and by probability of award. An overall contract direct resources forecast results from the combination of all activity forecasts.

Measurement of Marketing Personnel Effectiveness

The marketing group utilizes BUPAR to stay abreast of the performance of each salesman and contract administrator. In the forecast by sales personnel, each salesman lists his sales targets with the following information:

1) Estimated dollar value of the contract.
2) Probability of award to RCA.
3) Solicited or unsolicited.
4) Date a "request for quote" is expected (if the target is pre-proposal); *or* date proposal is due (if proposal activity has begun); *or* date proposal was submitted (if the proposal has already been prepared and submitted).
5) New or add-on.

With this information, the computer develops a sales forecast for each salesman and contract representative. At the end of each month, actual sales by salesmen and contract administrators are recorded on the master file. Actual sales, together with the latest forecasts, are compared against each salesman's annual quota. From this report, marketing managers know how much each of their men has sold plus how much more they expect to sell within the time frame covered by their quota. Timely sales performance information can assist the marketing managers in assigning sales personnel to specific programs, product lines, customers, etc.

From a comparison between forecasted contract direct resources and actual resources expended, engineering managers can locate wide variance areas. Usually, these variances are satisfactorily explained. Commonly an anticipated contract slips a couple of months from the estimated bookings data. In some instances, however, the variance results from problems that must be assessed in terms of the additional contract direct resources required to get back on schedule.

JAMES B. SAUNDERS graduated from the University of Rochester in 1960 with the degree of BA in Psychology and from Indiana University with the MBA in 1962. He joined RCA in 1962 as a trainee in the MBA Program of the DEP Communications Systems Division, completing three two-month assignments in manufacturing, operations control, and marketing. Mr. Saunders is now Administrator of the BUPAR system for the DEP Communications Systems Division. His present effort is directed toward implementing a comprehensive management-information system, of which BUPAR is an integral part.

JOHN H. DETWILER received his BSEE from Princeton University, and his MBA from Columbia University. He joined the DEP Communications Systems Division immediately upon graduation from Columbia University, with initial assignments in Marketing, Engineering, and Operations Control. He was subsequently appointed Manager of Planning of the DEP Communications Systems Division, responsible for financial and business plans. While in this position, BUPAR was developed and implemented. He was recently appointed Administrator, Budget Performance and Analysis, for the RCA Corporate Staff, responsible for development of new planning and control techniques throughout RCA.

L. to R.: E. E. Moore, Mgr. Engineering Design Support; W. F. Bell, Mgr. Marketing Planning; authors J. B. Saunders and J. H. Detwiler; and R. W. Greenwood, Mgr. Operations Control, all of DEP-CSD.

Allocation of Resources

Defense marketing departments generally play a major role in the allocation of two primary types of financial resources: 1) the marketing systems fund used to prepare proposals, and 2) the applied research and development fund with which technological capabilities are developed. BUPAR allocation data thus promotes more efficient bidding and research-and-development investment, enabling marketing to offer the military customer equipment which better suits his needs, and by so doing, arrives at a better position to compete for military business. Through a review of the description of potential business, marketing can better allocate these resources between departments and product lines. In the same manner, it is possible to allocate these funds within departments and product lines in the manner which promises to put the company in the best position to compete for future business.

ADVANTAGES

For overall top management planning, BUPAR provides answers to two of the problems inherent in some of the other "modern management" techniques:

1) BUPAR is oriented to the whole organization's activities, *not just to one program.* The new management-control techniques that are program-oriented must be implemented on *all* programs within an organization before they can satisfy top management's need to review their business *as an entity.* Yet, from a program point of view, it may well be neither necessary nor desirable to apply such control methods to *all* programs within the organization. Consequently, such systems can fail to furnish management with the information it needs to prepare *overall* marketing, personnel, technical, financial, and facility plans.
2) Other techniques often do not cover information on programs which are not yet in the proposal stage; that is, potential business. In the defense industry, very little advance planning can be done if the majority of the potential contracts are ignored simply because a proposal has not yet been prepared.

BUPAR does not replace any present program control system but can be used simultaneously with other systems, or alone. Since BUPAR presents information concerning individual programs in summary form only, there is practically no duplication of information between BUPAR and existing program control systems (PERT, e.g.). Other benefits of BUPAR are:

1) *Greater coordination between functional areas*—Because marketing, engineering, and production activities can use a common file of planning data, their forecasts are more coordinated.
2) *Reduced time required to update load report*—A draft engineering and production direct resources forecast containing the latest marketing revisions, deletions, and additions to anticipated business will be given to the person responsible for updating his activity's load. The draft forecast is reviewed for accuracy, clarity, and completeness. Necessary changes and comments are penciled in on the draft copy which is then returned to the BUPAR engineering and production representative.
3) *Greatly reduced clerical effort*—The computer accumulates, sorts, performs arithmetic operations, and classifies data into meaningful action forecasts and analyses.
4) *More timely bookings, billings and manpower forecasts*—Turn-around time to prepare these forecasts is reduced because an efficient procedure to feed inputs into the computer for processing is being followed.
5) *Standardized job identification*—Every potential or in-house contract is assigned one description which is printed out on each type of forecast. Thus, the problem of marketing, engineering, and production calling the same job by a different description is lessened.

The BUPAR system can provide top management with the timely and concise planning information previously developed only through a series of parallel report systems, with attendant savings in manpower and clerical effort, and the benefits of a coordinated base for long-term business planning.

DIRECTORY OF RCA LICENSED PROFESSIONAL ENGINEERS

ARE YOU REGISTERED? This Directory is based upon an auditing of previously published listings in the RCA ENGINEER, and is a compilation based solely on the voluntary submission of this information to our Editorial Offices. Therefore, if you hold a professional engineering license in any state (regardless of where you may actually now work) and your name does not appear below, then send your name, PE number (and state in which registered), RCA division, location, and telephone number to: RCA ENGINEER, Bldg. 2-8, RCA, Camden, N. J. As new inputs for this Directory are received, they will be published in future issues.

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HIGH-FIELD SUPERCONDUCTORS ...New Developments in Theory, Materials, and Applications

J. P. McEVOY, JR.
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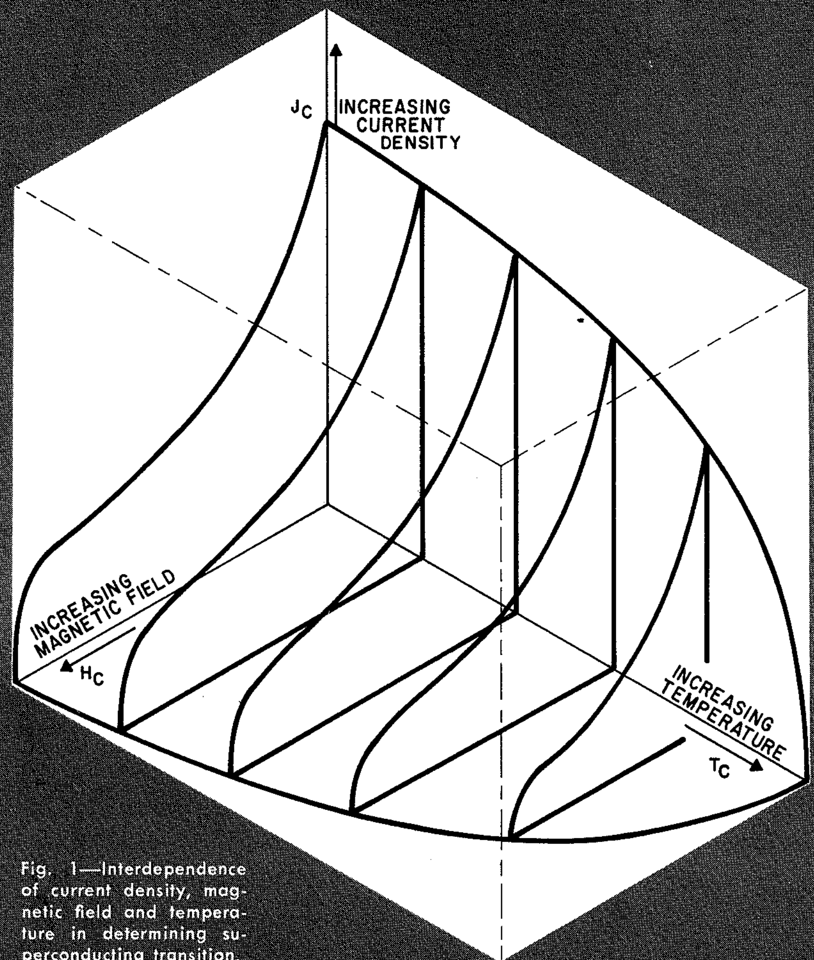

Fig. 1—Interdependence of current density, magnetic field and temperature in determining superconducting transition.

High-field, high-current superconductivity, i.e., the transmission of large DC currents through certain conductors in high magnetic fields with no electrical dissipation, was first reported in 1961. Since that time, considerable interest has developed in understanding and applying this remarkable phenomenon. The significant advances in this field during the past three years are reviewed here with regard to the important theoretical developments, the preparation of improved materials, and the practical uses of these materials in applications such as superconducting magnets. (A selected Bibliography is appended.) The importance of high magnetic fields for future power generation systems (magnetohydrodynamics and nuclear fusion), ultrasensitive receivers and amplifiers (masers), and plasma microwave devices has brought many new workers into the field. Our understanding of the basic mechanisms which cause high-field superconductivity is, to be sure, a prelude to the production of better materials for coil windings and reliable, extremely high-field superconducting solenoids.

PROGRESS in high-field superconductivity provides an example of how workers of various skills and training cooperate to promote a promising technology. Chemists and metallurgists concerned with the preparation of new and improved superconductors have been called upon to work intimately with physicists in attempting to understand the unusual electric and magnetic properties of these materials. Similarly, engineers responsible for producing practical devices such as magnets, have developed an astute appreciation of the most subtle superconductive phenomena in order to devise optimum design and construction principles.

A comprehensive introduction to the properties of superconductors has been adequately treated in a recent monograph[1] and is not necessary here. However, it is important that the conditions which affect superconductivity and also such notions as critical temperature, critical current density, and critical magnetic field be understood. The two-fluid model based on thermodynamics affords a convenient framework for a simple description of the transition characteristics of superconductors. This model applies only to the superconducting metals, i.e., the metals that undergo radical changes in their electronic properties when cooled to temperatures near absolute zero.

In the two-fluid model, the electron gas in the metal consists of two components, superconducting and normal. As the temperature is lowered to a certain value, the critical temperature, a fraction of the electrons begin to "condense" into a sort of ground state of lower energy. In this state, electrons do not participate in energy exchange such as thermal conductivity and specific heat. They are not scattered by the lattice, and consequently, they have no electrical resistance. It should be noted that superconductivity has many facets and certainly cannot be considered as merely the absence of electron scattering due to reduced thermal motion at low temperatures. However, for the purpose of this paper the complex interactions which actually cause the phenomenon may be overlooked.

As a result of the condensation process described above, there is a net difference in free energy between the two states. Any change in the environment which tends to increase the free energy

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of the superconducting electrons will decrease this difference, leading to destruction of superconductivity when the difference vanishes. Since the free energy of the superconducting phase depends on the current density and the magnetic field as well as the temperature, the critical current density J_c, the critical magnetic field H_c, and the critical temperature T_c are related. The curves of Fig. 1 show qualitatively this interdependence. Although these curves are not meant to present quantitative data, their general shape is that of a high-field, high-current superconductor in a transverse ($J \perp H$) magnetic field, the situation of interest in this paper. Any point inside the surface of the three-dimensional space bounded by the curves and the coordinate axis is superconducting, and any point outside is normal. Thus if one is to report on say, the critical current, he should specify at what temperature and magnetic field the measurement was made. With these thoughts in mind, a more detailed discussion of the magnetic properties of superconductors follows.

MAGNETIC PROPERTIES OF SUPERCONDUCTORS

For many years it was believed that superconductors differed from normal metals only in having zero electrical resistance, the resistance being restored to its normal value in the presence of a sufficiently intense magnetic field, i.e., the critical field. However, in 1933, Meissner and Ochsenfeld found that a solid cylinder of lead or tin, situated in a uniform applied magnetic field, expels the magnetic flux as the cylinder is cooled below the critical temperature. This transition to perfect diamagnetism is known as the Meissner effect. These joint phenomena of zero electrical resistivity and perfect diamagnetism characterize the superconducting state. Hans and Fritz London described these properties by proposing that the magnetic field does not disappear at the surface of a superconductor, but falls off exponentially with distance into the metal with a characteristic length, λ, called the penetration depth. A. B. Pippard of Cambridge University modified the London equations by considering the long-range interaction of superconducting electrons. He introduced a new characteristic length ξ, the coherence length. This is the distance necessary for a superconducting phase to vanish and a normal phase to appear in the interior of a metal. Pippard's experimental work showed the λ increased and ξ decreased as the electron mean free path decreased, i.e., as impurities were added to the metal. This work led to more detailed investigations of the surface energy of superconductors.

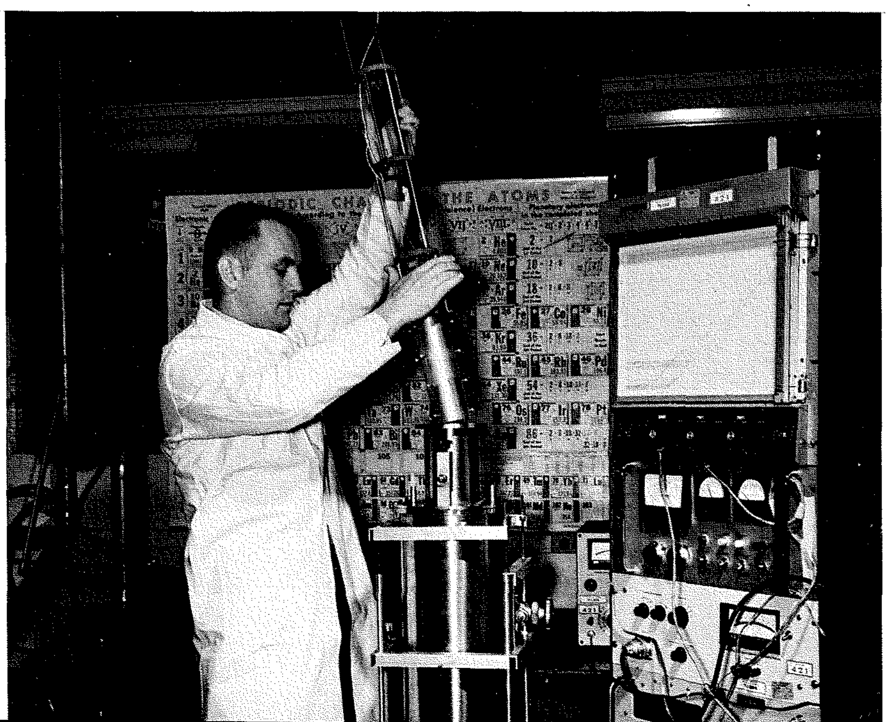
GLAG Theory

In 1950, two famous Russian physicists, V. L. Ginzburg and L. Landau, published a paper which gave the mathematical criterion for distinguishing between two types of superconductors, which they called type I and type II. This theory showed that when the penetration depth becomes larger than the coherence length, the surface energy between a normal region and a superconducting region in the metal is too small to withstand the pressure exerted by the magnetic field trying to enter the superconducting region. Consequently, the perfect diamagnetism breaks down and the field enters the material although the dc resistivity is still zero. It will be shown later that it is this efficient use of the superconductor's volume which permits the superconducting state to persist to very high magnetic fields. Metals exhibiting these properties are called superconductors of the second kind (type II).

The work of another Russian, A. A. Abrikosov, gave way to a clearer understanding of the magnetic behavior of type II superconductors. Using the guidelines of the Ginzburg-Landau theory, Abrikosov derived a model which described how type II materials behave in a magnetic field. Type I materials such as pure lead or tin (previously known as *ideal* or *soft* superconductors) when cooled below their critical temperature exclude magnetic flux in all fields up to a critical value H_c. Beyond

J. P. McEVOY, JR. received the BS in Physics from St. Joseph's College in 1959, and then joined DEP Applied Research, continuing his studies on the RCA Graduate Study Program. He obtained the MS in Physics from the University of Pennsylvania in 1962. Since joining RCA, he has studied various solid-state phenomena, such as photoconductivity, electroluminescence, and ferroelectricity. He was instrumental in the development of color electrophotography. In the computer field, he has worked on electro-optical random-access memories and thin-film switches for high-capacity cryogenic computers. In 1961, he attended a special course on superconductivity at MIT. Since early 1962, Mr. McEvoy has been investigating high-field superconductors and their application to new electronic devices. He has been responsible for the development of superconducting magnets for RCA's traveling wave maser. His work in this field led to collaboration with the RCA Laboratories and more basic studies of high-field materials, particularly NbZr and Nb_3Sn—including fundamental contributions to low-temperature magnetometry, critical current measurements of Nb_3Sn, and the effects of plastic deformation and neutron-irradiation-induced defects on the critical current of high-field superconductors. In March 1964, he was awarded a "David Sarnoff Fellowship" for the 1964-1965 academic year. He will begin study for his doctorate at the Imperial College of the University of London, specializing in low-temperature physics and physical metallurgy. He is a member of Sigma Pi Sigma and the American Physical Society.

J. P. McEvoy (author) inserting an iron-core superconducting magnet into a liquid-helium dewar. The magnet, precooled with liquid nitrogen, supplies a uniform, intense field for operation of a solid-state traveling-wave maser.



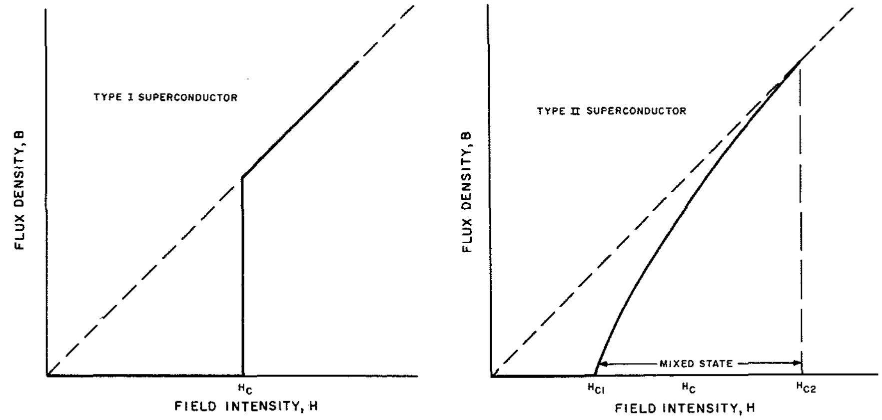


Fig. 2—Magnetization of superconductors.

H_c, flux completely penetrates the sample, normal resistance reappears, and the superconducting state is destroyed. Type II materials, on the other hand, completely exclude flux up to a field H_{c1}, but there is a *gradual* flux penetration thereafter until at a field H_{c2} penetration is complete and superconductivity is destroyed. In the region between H_{c1} *and* H_{c2}, called the *mixed state*, magnetic flux reversibly enters and leaves the type II material without destroying superconductivity.

Fig. 2 shows the magnetization curve for the two types of materials considered by Abrikosov. The magnetic flux density in the body of the superconductor is denoted by B and the applied field is denoted by $\bar{H}$. Note that these curves are reversible.

The basic ideas of the theoretical development just described comprise the GLAG theory, named for Ginzburg, Landau, Abrikosov and Gor'Kov, the latter being included for showing that the results are consistent with the microscopic theory of superconductivity (BCS theory) due to Bardeen, Cooper, and Schreiffer. The GLAG theory has been verified recently by a body of sensitive calorimetric experiments and magnetization studies on pure type II samples.[2]

Hard Superconductors; Tube Magnetization

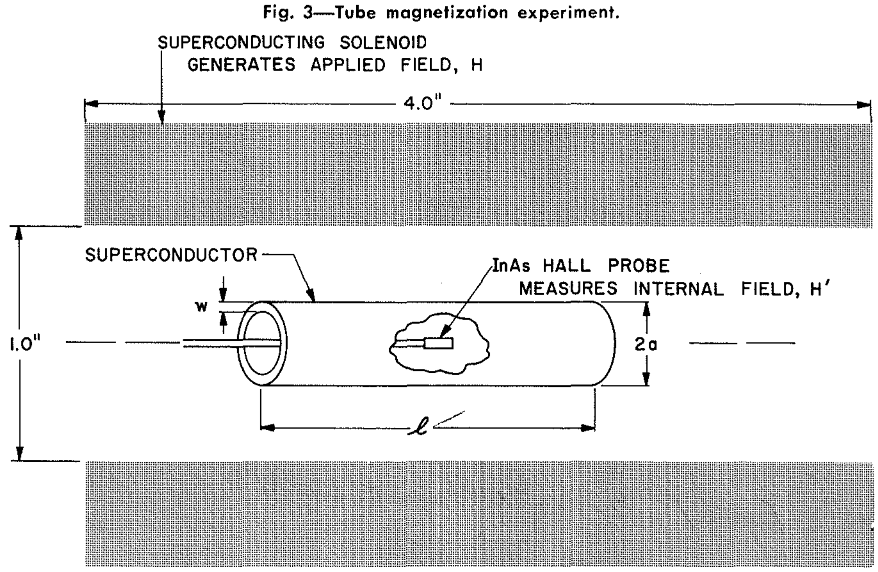
The next step in understanding high-field superconductivity was to explain the large magnetic hysteresis and trapped flux in the magnetization of some type II superconductors and account for the large range of critical currents observed in similar materials. A recent phenomenological theory, developed mainly by Y. B. Kim and P. W. Anderson of the Bell Telephone Laboratories, has been most successful in this regard.

A very useful relationship regarding the critical current density as well as many important qualitative features about *hard* superconductors were formulated by Kim and coworkers from observations made on a simple experiment known as tube magnetization.[8] (*Hard* superconductors are type II materials which are saturated with defects and can thus carry large currents.) Using this technique, the critical current density J_c and its field dependence can be determined inductively by measuring the penetration of a longitudinal field into a hollow cylinder (tube) made from a superconductor. The relationship,

$$J_c = \frac{\alpha_c}{H + B_o} \qquad (1)$$

(where α_c and B_o are constants) was found to accurately describe the experimental data for many hard superconductors such as niobium-tin (Nb_3Sn) and niobium-zirconium (NbZr). The equation applies only when the sample is in the critical state that is when each region is carrying its maximum current determined by the local magnetic field.

Fig. 3—Tube magnetization experiment.



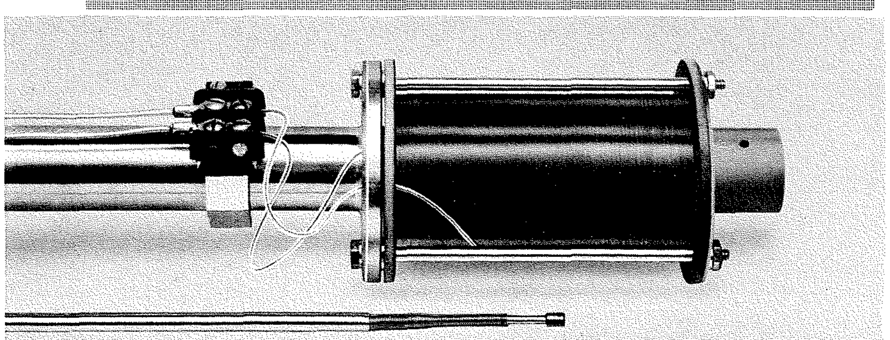
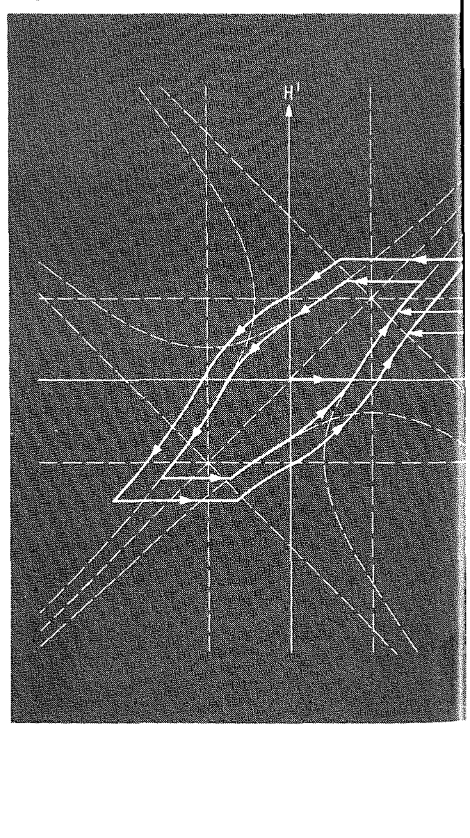


Fig. 4—Analytical curves (H' vs. H) for tube magnetization.



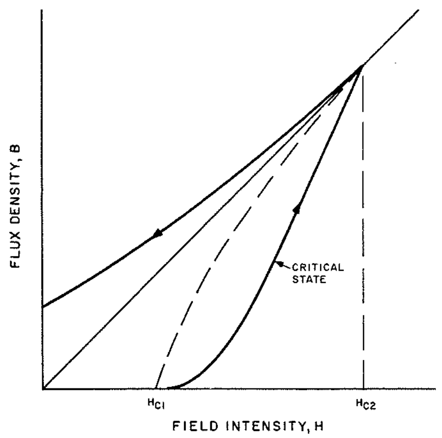


Fig. 5—Magnetization of type II superconductor with defects.

Fig. 3 shows the experimental method. As the applied field H builds up, current is induced in the tube walls by Lenz' law keeping the internal field H' at zero. However, when the superconductor reaches its limiting current, that is, when it enters the critical state, it becomes porous to the field and H' begins to increase. The resulting H'-vs-H curve fits a theoretical plot remarkably well if the relationship above is used for the field-dependent current density which accounts for the difference between H and H'. Fig. 4 shows an analytical plot of H'-vs-H critical-state curves for two different values of α.

Lattice Imperfections, Lorentz Force, and Flux Creep

Another important aspect of this development was the effect of lattice defects on magnetization and critical currents. In this regard, the work of B. B. Goodman should be mentioned. He first suggested that defect-saturated alloys and compounds such as NbZr and Nb_3Sn were actually nonideal type II superconductors,[4] i.e., they are hard superconductors.

A paper by P. W. Anderson published in 1962[5] gave a logical explanation of the critical state phenomena observed by Kim, et al. in terms of the Abrikosov model. Anderson assumed that there is a pinning force or energy associated with each defect which impedes the motion of the flux. Thus, the magnetization of a type II superconductor containing a small percentage of lattice defects such as dislocations, grain boundaries or voids, deviates from ideal reversible behavior. Fig. 5 shows a sketch of the magnetization of a type II superconductor indicating qualitatively the effect of the defects. Notice that the flux does not enter the body of the metal precisely at H_{c1}, since its motion is resisted by the pinning action of the imperfections. As the field increases, the flux is kept out until all the pinning centers are filled. At this point, which is another way of defining the critical state, the field enters the sample, proceeding toward complete penetration at H_{c2}. The pinning action also results in partial trapping of the flux in decreasing fields as shown in Fig. 5.

In ideal type II materials, the internal flux of the mixed state moves freely about under the action of the mutually repulsive forces of the flux lines. Consequently, nonuniform distribution of flux corresponding to spatial variations of the field, and thus bulk currents, would be quickly smoothed out. For magnetic hysteresis and persistent bulk currents to exist, the flux motion must be limited by the structure of the material, for example, by the pinning action of the lattice imperfections. Anderson's theory postulates that field gradients and currents are not quickly smoothed out in hard superconductors because of the defect pinning. Thus, lattice defects are essential for stabilizing the superconducting phase in a magnetic field when the sample is carrying a large current. With no pinning centers, the Lorentz force, $J \times B$, would sweep out the superconducting regions, causing heating and a transition to the normal state.

The importance of the Lorentz force in determining the magnetic properties of hard superconductors has been emphasized by the success of the Kim-Anderson theory. First, the relationship given in Eq. 1 shows that $JH = \alpha =$ *constant* for moderately high fields $(H > B_o)$, indicating that the Lorentz force does in fact determine the current transitions of hard superconductors. A simple test for the validity of this is to consider the case in which current is supplied externally to a superconducting strip that can be rotated in an applied magnetic field. The simplest modification of Eq. 1 to take into account the nonperpendicular field is

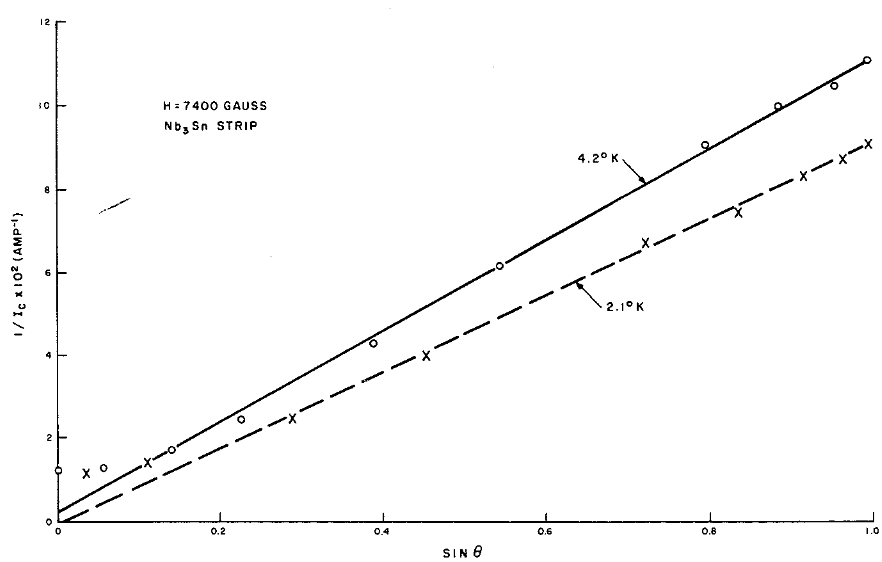
$$J_c = \frac{\alpha_c}{H \sin \theta + B_o} \qquad (2)$$

Where: θ is the angle between the field and the axis of the strip. From the expression above, it is easily seen that the reciprocal of the current at constant field H, should be proportional to sin θ, since α and B_o are constant. Fig. 6 shows such a plot for a vapor-deposited strip at 4.2 °K and 2.1 °K which has been rotated through 90° in a field of 7,400 gauss. This result, which was recently reported by G. W. Cullen, G. D. Cody, and the author,[6] is strong support for the Lorentz force arguments of Kim and Anderson.

A further consequence of Anderson's work is the notion of *flux creep*, by which the magnetic flux moves slowly over the pinning barriers under the action of the Lorentz force aided by the thermal energy, KT. Thus, in an absolute sense, there is *some* resistivity, since persistent currents do decay and heating does occur. The important conceptual benefits of this theory are discussed later.

On the basis of the flux creep model the physical meaning of the current density has been clarified by use of the Lorentz force parameter α and its relationship to the pinning defects. To a rough approximation, the critical Lorentz force will be somewhat proportional to the product of the pinning strength of the defect and the defect density. Thus, the introduction of de-

Fig. 6—Evidence for Lorentz force quenching in Nb_3Sn strips.



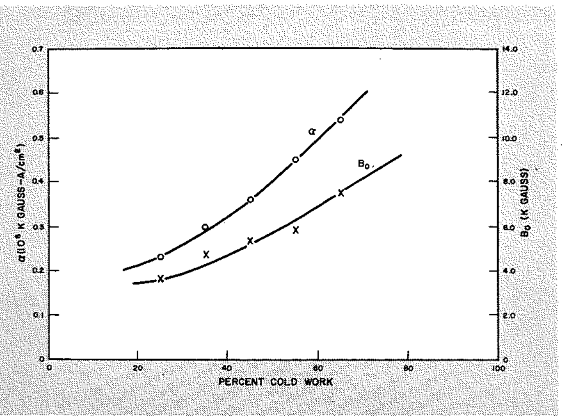


Fig. 7—Variation of critical parameters in NbZr with cold work.

fects into a hard superconductor should increase its critical current.

The author and coworkers have investigated the effect of plastic deformation[7] and neutron irradiation[8] on the critical current density of NbZr alloys and the intermetallic compound Nb_3Sn. Fig. 7 shows the increase of the critical state parameters α_c and B_o for a NbZr alloy as a function of cold work. It is believed that the cold reduction introduces dislocations and grain boundaries into the microstructure which act as new pinning centers. These samples were taken from a single ingot of (Nb 25% Zr) and cold-reduced by swaging to the identical geometry. The constants were determined by the tube magnetization technique previously described. Since intermetallic compounds such as Nb_3Sn cannot be cold-worked due to their brittle composition, fast-neutron irradiation was used as a technique for introducing defects and increasing the current carrying capacity.

Fig. 8 shows the change in the critical state curve for a vapor-deposited Nb_3Sn tube irradiated with 10^{18} fast-neutrons/cm^2. It is estimated that α_c and, consequently, J_c have increased by about 50%. Radiation damage and subsequent annealing can thus be used to achieve the desired microstructure for optimum trade-off between maximum critical current density and minimum instability. Annealing studies indicate that the defects produced by the neutron bombardment can be annihilated quite easily. A more detailed study of the kinetics of irradiated Nb_3Sn, including transmission electron microscopy, should yield fundamental information on the nature of the induced effects. The high degree of atomic ordering in vapor-deposited Nb_3Sn was the main reason for such large effects. Negligible changes in J_c were observed in NbZr alloys. The increase in critical current of hard superconductors by neutron irradiation was first achieved by a team of investigators from DEP Applied Research and the RCA Laboratories.

HIGH-FIELD SUPERCONDUCTING MATERIALS

Alloys

A great deal of research and development on the preparation of materials to be used for making superconducting windings has been performed since the two principal materials, niobium zirconium and niobium tin, were reported.[9] Niobium zirconium is a strong, ductile alloy which is relatively easy to prepare and draw into wire. Its current carrying properties are, however, extremely sensitive to metallurgical variables such as composition, heat treatment, and mechanical working which includes the wire drawing process itself. In spite of this, high-quality NbZr wire is presently available in single lengths to 10,000 feet or more for use in winding magnets. Recent studies of this alloy have shown that its current carrying capacity can be increased by careful heat treatment during the wire drawing process. Even further increases result from a final vacuum heat treatment (600 °C to 800 °C) after the last cold reduction. To compare the relative merits of superconducting materials, the critical current density of the wire in a transverse magnetic field is measured as shown in Fig. 9. Data typical of commercial grade NbZr wire in short straight samples is given here. However, when this wire is wound into an inductive coil, it carries only about 50% of the straight sample current. This is known as the degradation effect and is particularly troublesome in NbZr. Note in Fig. 9 that the lower critical current for NbZr wire solenoids.

Because of the closely controlled and expensive processing required to produce high quality NbZr and the "degradation" of its current carrying capacity when wound into coils, other superconducting alloys have been investigated. One in particular, the binary

Fig. 8—Effect of neutron irradiation on Nb_3Sn critical state.

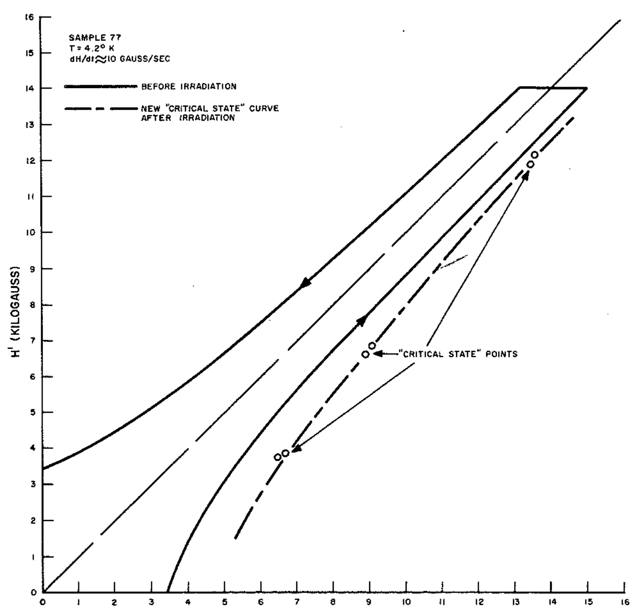
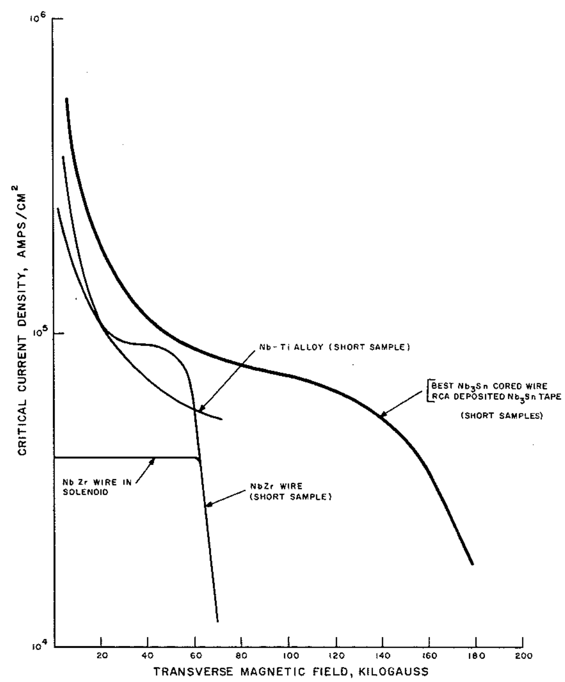


Fig. 9—Critical current density of superconducting wire and ribbon.



system of niobium and titanium is interesting since its upper critical field is greater than 100 kilogauss. Although the critical current density of NbTi wires is typically lower than NbZr (see Fig. 9), coils made with NbTi wire do not exhibit sizable degradation. Thus, the NbTi alloy not only carries significantly greater current in a coil at a given field than alloys of the NbZr system but it also remains superconductive in much higher fields. The superior coil performance of this alloy has been used in the construction of a practical 100-kilogauss superconducting solenoid (see Table I).

Intermetallic Compounds

Unusual metallic compounds such as vanadium-gallium (V_3Ga) and niobium-tin are the most promising superconductors yet discovered. The critical temperature of Nb_3Sn has been measured at above 18 °K, and specific heat measurements indicated that V_3Ga has a critical field of about 500 kilogauss. Although the difficulty in preparing these compounds has discouraged their widespread use, much effort has been devoted to the preparation of special "wires," particularly of Nb_3Sn. The critical current density of Nb_3Sn is slightly higher than NbZr, but more important is the fact that it maintains its zero DC resistivity to approximately 200 kilogauss.

Fig. 9 shows the critical current density of Nb_3Sn as a function of the applied magnetic field at 4.2 °K. The current density is calculated on the basis of the total wire cross-section such that the curve takes into account space factors due to the wire composition. It is apparent that for fields of 60 kilogauss or lower there is a choice of either NbZr or Nb_3Sn, since their critical current densities are comparable.

One of the early processes of producing Nb_3Sn wire was the "core" technique.[10] This involves packing mixtures of niobium and tin powders in niobium tubes and drawing the composite down to wire. Subsequent heating to about 1,000 °C forms the compound Nb_3Sn in a core surrounded by a sheath of niobium. The major disadvantage of this wire is that heating must take place after the wire has been wound into its final configuration since it is extremely brittle in the reacted condition. Other attempts to produce useful Nb_3Sn wire have included diffusing tin into thin niobium ribbons, dipping niobium wires into tin and reacting the wires after winding, and vacuum impregnating tin-dipped niobium wires in a niobium tube before drawing and reacting.

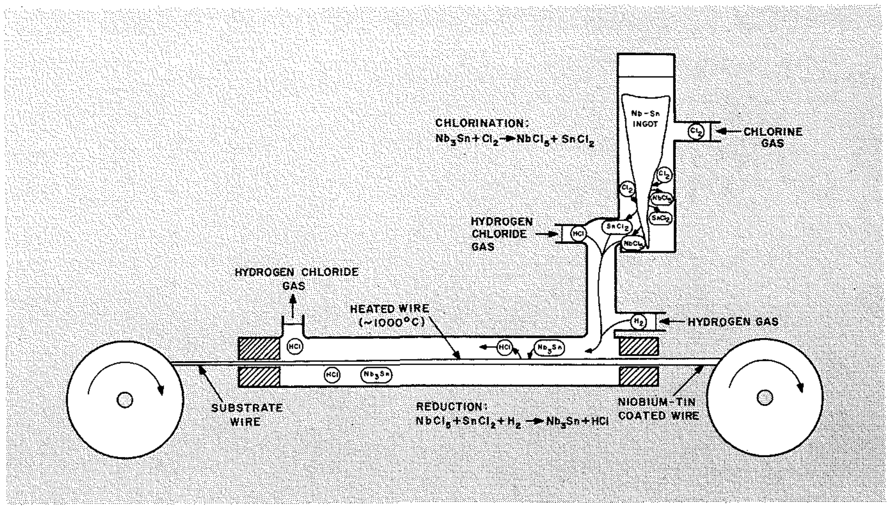


Fig. 10—Continuous vapor deposition of Nb_3Sn wire or ribbon (after Cody, Hanak, et al).

Perhaps the most significant advance in the preparation of high-field superconducting materials is the vapor-deposition process for Nb_3Sn reported by J. J. Hanak of RCA Laboratories.[11] In this process the material is prepared by the simultaneous hydrogen reduction of niobium and tin chlorides onto a variety of substrates. The deposit, which is polycrystalline and single-phase, has the highest critical temperature (18.2 °K), critical current density (10^5 amp/cm^2 at 100 kilogauss), and critical field (>200 kilogauss) ever reported for a useful superconductor. The process, which is shown schematically in Fig. 10, has been made continuous, and great lengths of superconducting ribbon have been produced, formed by the deposition of thin films onto stainless steel tape.[12] This technique eliminates most of the undesirable features previously observed for Nb_3Sn. Coils may be wound from this ribbon *after* it has been processed, unwound, and rewound if necessary. Further, the current-carrying capacity of these films is so high that in spite of the low space factor (ratio of superconductor cross-section to total wire cross-section), the deposited tape carries as much current per conductor area as the best "cored" wire made to date (see Fig. 9). Characteristics of coils made from RCA tape are described in the next section.

SUPERCONDUCTING MAGNETS

It is obvious from the existence of permanent magnets that energy need not be expended in sustaining a steady magnetic field. The power required to operate conventional electromagnets is necessary only because of the resistive losses in the coil windings. Thus, it is not surprising that the concept of using superconductors for generating magnetic fields is as old as the phenomenon itself. Kamerlingh Onnes, who first liquefied helium and discovered superconductivity in 1911, attempted to fabricate a solenoid but soon realized that superconductivity and magnetic fields were incompatible. Of course, his materials were of the type I variety and had critical fields of only a few hundred gauss.

TABLE I—Some Recently Reported Small-Volume Coils

	Winding Material	*Coil dimensions (inches)*			*Number of sections*	*Max Field (gauss)*	*Temperature (°K)*	*$\Phi = BA$ (Maxwells)*
		i.d.	*o.d.*	*length*				
RCA	0.002" x 0.087" vapor-deposited Nb_3Sn tape (3,520 ft)	0.50	3.85	2.0	4	92,000	4.2	117,000
General Electric	0.027" tin-clad niobium wire† (600 ft)	0.32	2.19	1.78	2	101,000*	1.8	53,000
Westinghouse	0.010" Nb 40% Ti wire	0.125	7.0	6.0	?	100,000	4.2	6,350

* Destroyed after single quench
† Wire reacted after coil was wound

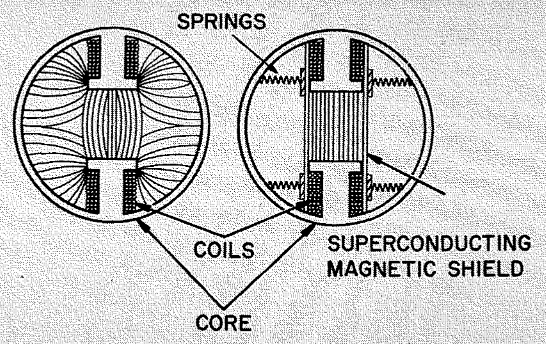


Fig. 11—Elimination of fringing fields using superconducting shields.

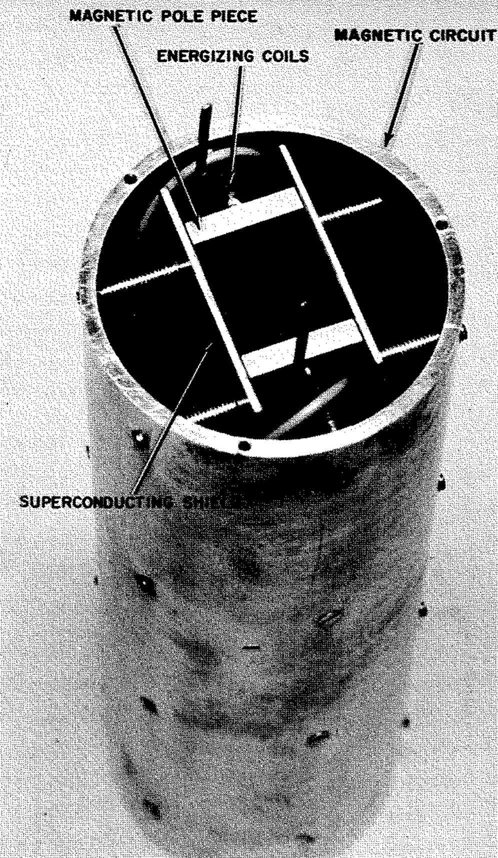


Fig. 12—Traveling-wave-maser magnet.

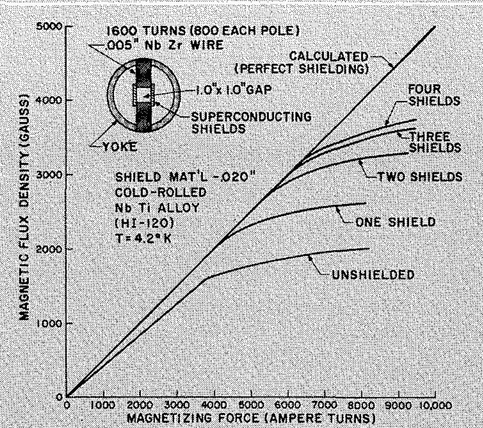


Fig. 13—Dependence of gap field on shielding thickness.

Materials in use today, and most notably Nb_3Sn, are capable of providing magnets of 200 kilogauss. In fact, despite the many unforeseen problems inherent in the fabrication and operation of high-field solenoids, astounding progress has been made.[13] Table I lists the details of construction of several small-volume coils recently demonstrated by various research laboratories. For purposes of comparison, it is interesting to calculate the total useful flux generated by each coil. This is an indication of the relative size of the solenoids. A review of the work that went into the development of the solenoid reported by RCA is given in Ref. 14 and 15.

Recent success in understanding the cause of current degradation in superconducting solenoids led to the realization of 100-kilogauss magnets. To appreciate the magnitude of this achievement, consider the 88-kilogauss, 2.0-inch-inner-diameter copper solenoid at Bell Telephone Laboratories. This coil dissipates a steady power of 1,600,000 watts and requires 1,000 gallons of water per minute for cooling.

The realization that degradation in coils is caused by the interaction of heat generated by the motion of flux through the windings with the transport current in the wire has no doubt been inspired by the flux creep theory. Anderson showed that there is a finite diffusion of flux density B in hard superconductors and derived the power dissipation (due to flux creep) using Maxwell's equation:

$$\overline{\nabla} \times \overline{E} = \frac{1}{c} \frac{\partial \overline{B}}{\partial t}$$

Since $\partial \overline{B}/\partial t$ is non-zero there is an electric field in the superconductor which cause losses $P = \overline{E} \cdot \overline{J}$, where J is the transport current density. The same fundamental ideas probably apply to the macroscopic case of flux penetration through the magnet windings. If the process is slow and the flux diffuses smoothly, and if adequate cooling is provided, the field will be maintained. However, large "flux jumps" resulting from local buildup of the field at interior points of the windings usually result in a quenching of the magnet. This effect is being avoided in present magnet technology by exploiting the increased performance of high-field superconducting solenoids using the technique of magnetic field stability.[15] Solenoids are fabricated such that the outer windings are independent of the inner windings. By energizing the outer solenoid first, the inner coils are placed in a magnetic field before being energized, stabilizing the current. Significantly higher current can thus be carried by the inner windings since flux jumping is eliminated.

Traveling-Wave Masers

DEP Applied Research has been concerned with the use of superconducting magnets in traveling-wave maser (TWM) systems.[16] A 6-inch maser which employs a meander line as a slow-wave structure and chromium-doped rutile as the paramagnetic crystal has achieved amplification in excess of 25 db over a 50% tunable bandwidth with a superconducting magnet. Consequently, this device is of major interest for military and commercial interest such as tracking radar systems, radiometry and sensitive microwave communication systems.

The magnetic field requirements of a TWM are severe, since moderately high fields (2 to 5 kilogauss) of great uniformity (1 part in 1,000) must be generated over a volume of approximately 6 cubic inches. Space and weight reductions of nearly two orders of magnitude have been achieved by using superconducting wire wound on a ferromagnetic yoke which was shaped to fit snugly around the maser. Vital to the operation of this device are superconducting shields, first discussed by Cioffi,[17] which enclose the field within the gap space and eliminate the fringing flux as shown in Fig. 11. A photograph of a typical magnet is shown in Fig. 12. The use of hard superconductors for the shield material allows for containment of reasonably high fields which can be used for a variety of masers. Fig. 13 shows the variation of the gap field as a function of the magnetizing force as more shields are pressed around the gap. This measurement[18] indicates again the phenomenon of the critical state, the point where the field penetrates the superconductor. The shields are cold-rolled niobium titanium alloys of 0.020-inch thickness which are bent to fit tightly around the pole pieces and are spring loaded to insure a good fit at low temperatures.

The use of the high-field superconducting shields, superconducting windings and special magnetic alloys for the core and pole pieces has made it possible to fabricate lightweight, compact magnets which provide the necessary fields for 6-inch masers. These magnets weigh as little as 5 pounds and have great potential for use in field operation with closed-cycle helium refrigerators.

CONCLUSIONS

In the past few years, progress has been made in high-field superconductivity that will have a permanent effect on the subject. The successful application of the Ginzburg - Landau - Abrikosov - Gor'Kov (GLAG) theory to a series of magnetic and thermal experiments has eliminated any doubt concerning the validity of this treatment in explaining the behavior of the two distinct types of superconductors.

Another recent breakthrough has been the description of the properties of non-ideal high-field superconductors in terms of the GLAG theory. This is important because practical materials used in winding magnets are in this category. The role of the Lorentz force in determining the critical current in a magnetic field has made necessary new criteria for quenching of hard superconductors. In addition, it is now known that lattice defects increase the current carrying capacity of high-field materials, although much work has yet to be done to improve our understanding of this effect. These advances have given great insight into the behavior of superconducting magnets. Power dissipation due to flux motion through the windings is most likely the major cause of current degradation in superconducting coils. Since the rate of heat diffusion in hard superconductors is so low, careful attention must be given to the cooling of the magnet windings.

Elucidation of the major problems associated with the construction and operation of high-field solenoids has led to a feeling of optimism regarding the realization of large volume coils of 100 kilogauss or more. Consequently, the next few years should find the departure of superconducting magnets from the realm of research into development and design. Nevertheless, superconductivity should continue to be an exciting research area as new phenomena are discovered at a prodigious rate. Recent reports of surface effects in type II superconductors[19] and superconducting semiconductors[20] are good examples.

Except as a research tool, high field magnets are not useful per se. The real test of their usefulness lies in applying them to systems in which it appears that great advantages in weight, volume, or economy can be achieved. These include such novel concepts as magnetic shielding of spacecraft to protect astronauts from radiation during interplanetary space travel, magnetohydrodynamic generators, and containment of thermonuclear plasma for fusion experiments. Coils are presently being conceived for inductive energy storage and improved operation of bubble chambers, electron microscopes and particle accelerators. Superconducting magnets for traveling wave masers are already in use.

RCA has invested a great deal of effort into research and development on high-field superconductors. The work of the RCA Laboratories, in discovering and investigating the properties of vapor-deposited Nb_3Sn; RCA Electronic Component and Devices, in constructing and operating a 92,000-gauss superconducting solenoid; and DEP Applied Research, in applying superconducting magnets to traveling wave masers, guarantees that this investment will be a sound one.

ACKNOWLEDGEMENT

Acknowledgement is made to co-workers R. F. Decell, Dr. G. W. Cullen, Dr. R. L. Novak and L. C. Morris who contributed to much of the experimental work reported here, and to L. J. Krolak for his encouragement and advice. In particular, the author is grateful for the opportunity of working with Dr. G. D. Cody of the RCA Laboratories.

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THE EPITAXIAL LAYER—A MAJOR CONTRIBUTION TO DEVICE TECHNOLOGY

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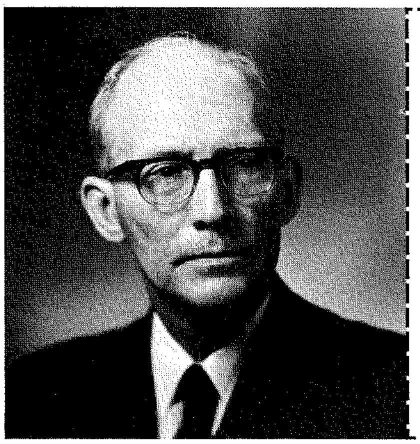
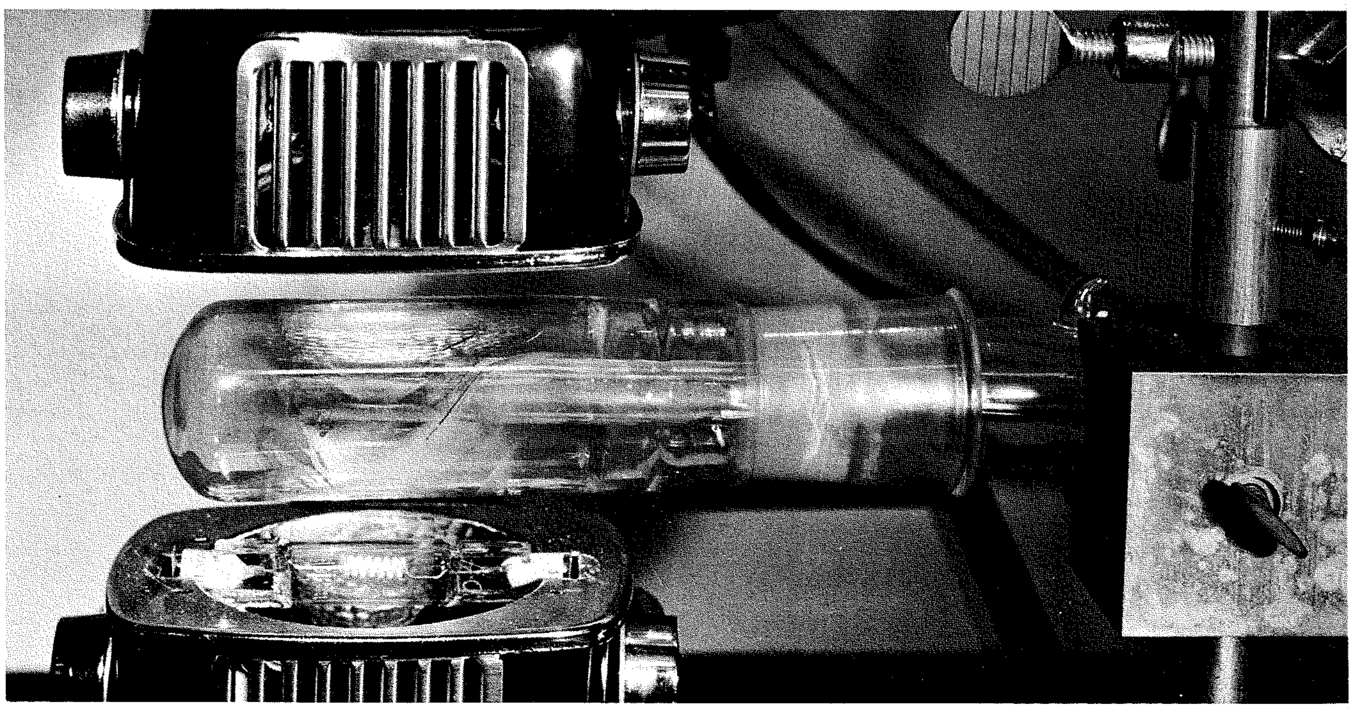
RCA is a leader in the use of the "epitaxial" technique—the most significant advance in semiconductor technology of recent years. A crystalline epitaxial layer is grown, simply and rapidly, on a crystalline base. The grown layer can be very thin (a microinch, for example); it can be of the same material as the base, but doped entirely differently, or it can be of a different material. There is no other way to prepare such a thin layer and obtain such an abrupt change in doping at the interface. Most of Somerville's new production bipolar silicon transistors use epitaxial layers. A large fraction of the new semiconductor devices under development in RCA Laboratories are based on epitaxial techniques; examples are improved solar cells, and the electrically pumped diode lasers that can be modulated by merely varying their input currents.



DR. J. S. DONAL, JR. received the BA in electrical engineering in 1926 from Swarthmore College and then received MS and PhD degrees in physics in 1927 and 1930 from the University of Michigan. During the period 1930 to 1936, he was a Fellow of the Johnson Foundation for Medical Physics and a Research Associate in Pharmacology, at the University of Pennsylvania. He then joined the Research Department of the Electron Tube Division, Harrison, and in 1942 moved to RCA Laboratories, Princeton. From 1936 until 1953, Dr. Donal's work was in the fields of television light valves, pulsed and CW magnetrons, and the modulation of CW magnetrons. He has published papers and contributed chapters to books on these subjects, and has written papers in the field of medical physics. In 1953, Dr. Donal was appointed Administrator, Research, in RCA Laboratories and in 1959 he became Administrator, Special Programs, on the staff of the Vice President, RCA Laboratories. He is a member of Sigma Xi. A Senior Member of the IEEE, Dr. Donal is a member of the Admission and Advancement Committee and Past-Chairman of the Princeton Section. He also serve as a member of the Board of Technical Advisors of RCA Institutes.

Fig. 1—Apparatus for growing epitaxial layers by the simplified close-spaced method (reprinted, by permission, from the Journal of the Electrochemical Society, November, 1963). Quartz tube in center contains substrate wafer, spaced 10 mils from a source wafer (polycrystalline, or a layer of powder). The infrared lamps above and below the quartz tube heat the substrate and source wafers. This simple, compact setup (developed at RCA Labs) has been an important factor in research on epitaxy.



SUPPOSE for the moment that you are an engineer working on semiconductor devices, and that you have been asked to construct a new high-frequency diode. This diode is to consist of a 1/16-inch-square layer of one semiconductor on a single-crystal supporting wafer made of a *different* semiconductor. The layer must be only 1 mil thick and this thickness must be uniform to a thousandth of a mil. In addition, the crystal structure of the layer must be an exact continuation of the crystal structure of the support, i.e., the rows of atoms in the layer must be *registered* with the rows of atoms in the support. Finally, the "doping" must be radically different in the thin layer and in the supporting wafer, with an abrupt change in the doping concentration at the interface.

How would you do it? Etch and polish a chip of semiconductor to a thickness of 1 mil and cement it to the base? This would not be a very promising approach, because even if the layer did not crack during handling, you would still face the problem of registering the rows of atoms and the difficulty that any cement would impede the motion of the current carriers across the interface.

As recently as four years ago, the task would have been hopeless; but today, we can make the structure relatively easily and even add a second thin layer of still another semiconductor. The secret is to use the crystalline support as a "seed," and to *grow* the thin layer in such a way that it automatically forms a perfect continuation of the crystal structure of the support. The process is called *epitaxial growth*, and the grown layer is called an *epitaxial layer*.

The word *epitaxy* is derived from the Greek roots *epi* (upon) and *taxis* (arrangement). An epitaxial layer is therefore a layer arranged on a support, in this case the base wafer or substrate.

Under a strict scientific definition, an epitaxial layer must be a *perfect* crystal, with a crystal structure not only in an orientation determined by the crystal structure of the support but *identical* in every respect with the structure of the support. This definition is a little too restrictive, however, because to meet all of these requirements the grown layer would have to be of the same semiconductor as the base (germanium grown on germanium, for example).

The definition is normally relaxed, therefore, and a layer is called epitaxial if it is the same crystal species as the support, and the rows and planes of atoms are parallel on both sides of the interface, although the atomic spacings on the two sides differ by a few percent.

Final manuscript received October 23, 1963

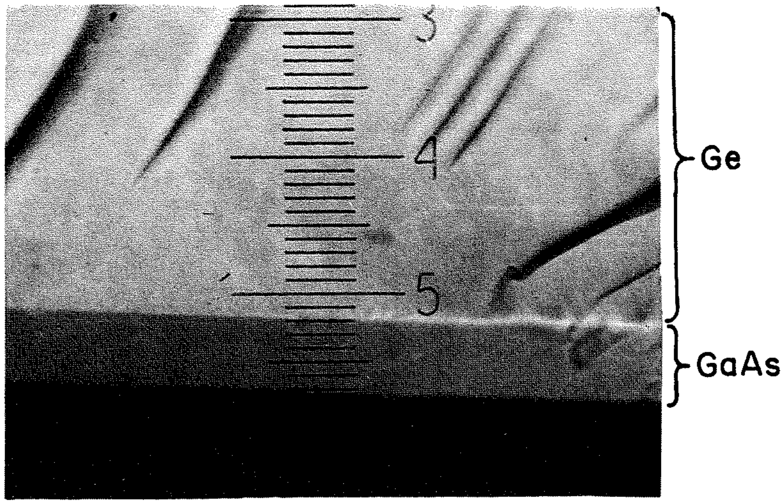


Fig. 2—Photomicrograph of a cleaved section of an epitaxial layer of gallium arsenide on a germanium support. The layer of gallium arsenide is approximately a thousandth of an inch thick.

This permits us to speak of an epitaxial layer of gallium arsenide on germanium, even though the atomic spacing in gallium arsenide is 0.05% less than in germanium. This difference in spacing gives strains in the first few atomic layers of the gallium arsenide, which take the form of the addition or omission of a row of atoms every so often. However, these strains extend only a fraction of a microinch into the epitaxial layer of gallium arsenide and from then on the layer is a perfect single crystal.

But there is a limit to the relaxation of the definition of an epitaxial layer. The grown layer *must* be a single crystal whose orientation is determined by the structure of a single crystal support. When the atomic spacings in two different materials differ by more than a few percent, the top layer usually breaks up into many small crystallites with no close relationship to the crystal structure of the support. The layer is no longer epitaxial. Similarly, if the support is not a single crystal, but is an amorphous material such as glass, the grown layer will again be made up of small crystallites. A useful device might be formed from this layer, but it is *not* an epitaxial layer.

ADVANTAGES OF EPITAXIAL LAYERS

Almost all semiconductor devices require a *junction*, i.e., an interface between two semiconductor regions doped with different impurities so that one region is n-type (current carried mainly by electrons) and the other region is p-type (current carried mainly by holes). A diode uses a single junction, while a transistor uses at least two junctions.

Often, as in the case of transistors, the semiconductor between the two junctions must be very thin to permit high-frequency performance by reducing the time of passage of the current carriers. Furthermore, performance can often be improved by an abrupt change in doping concentration from one semiconductor region to another. In the past, the doping impurities have been introduced by a diffusion process. This process gave us good devices, and still does, but it is hard by diffusion to form thin n- or p-type regions, and almost impossible to obtain an abrupt change in doping from one layer to another.

The very nature of an epitaxial layer makes it easy to solve these problems, for the epitaxial layer is a *new* layer added by growth at temperatures too low for significant diffusion. The layer can be as thin as desired—a microinch, for example. Since the doping impurity is introduced into the layer during growth, the change in the doping from the layer to the substrate can be extremely abrupt.

Next there is the matter of making a junction between two *different* semiconductors, which we believe will give us transistors, solar cells, and lasers with improved performance. In the past, no satisfactory way to make such a junction between two different semiconductors has been available. But epitaxial growth is solving this problem also, since the grown layer can be of a different material if its crystal structure does not differ too much from that of the support wafer.

There is a third major advantage of epitaxial growth. For most semiconductor devices, we must use single-crystal material in order to attain good performance. But several semiconductors that theoretically should make improved devices can be grown in single-crystal form only with great difficulty by conventional methods. Fortunately, we are finding that nearly all of these materials can be grown relatively easily as thin epitaxial layers on a support of a well-known, easy-to-crystallize semiconductor.

Our ability to use epitaxial growth to provide thin layers, to give abrupt changes in doping concentrations at the interface, to prepare junctions from different materials, and to prepare new, untried materials are advantages that provide increased freedom to device-research scientists and to design engineers. It is convincing evidence of the practical utility of epitaxial layers that they are present in most of Somerville's new production bipolar transistors, and that they have been used by Somerville to fabricate both high-voltage and high-power varactor diodes.[1,2]

HOW EPITAXIAL LAYERS ARE MADE

No one person invented the epitaxial layer. Rather, it evolved gradually from the work of many men, during many years, in university and industrial laboratories. Finally, epitaxial growth moved from the realm of experimentation by research chemists to its first application to electronics.[3] At that time the layers were grown by supporting the base wafers in a long, evacuated enclosure, usually made of quartz. The original apparatus, first applied to the preparation of germanium transistors, was inconvenient in that the reaction system had to be disassembled to retrieve the grown layer or to change its ingredients.

For the vapor-phase techniques, the general type of chemical reaction has remained unchanged from the earliest method to the latest methods described below, but improved techniques now give superior layers in a shorter time, and permit these layers to be made of a wide choice of semiconductors. The source of the epitaxial layer's ingredients, often an imperfect crystal or a powder of the semiconductor, is held at a high temperature and the crystal substrate is held at a lower temperature. A transport agent (such as iodine or chlorine) combines with the source material, carries it to the growing layer, and then repeats its transport cycle.

When we recognized, quite early, that epitaxial layers would be important in the fabrication of semiconductor devices, it was possible to build on original work performed at Laboratories RCA, Ltd., Zurich, on the growth of crystals by transport reactions similar to those that provide epitaxial layers. As a result, scientists in RCA Laboratories and in Somerville have since improved the methods for growing epitaxial layers, particularly by the introduction of a continuous-flow process.[4] In this procedure, the doping impurity—and even the semiconductor material itself—can be changed without stopping the process. Refinements are being added continually; an example is a method of preparing smooth, clean substrates that provide layers of much better quality.[5,6]

More than three years ago,[7,8,9] a method of growing epitaxial layers from a solution of the ingredients was developed in RCA Laboratories. This method is particularly suited to growing layers of heavily doped high-conductivity material. Somerville has used this solution growth for some time for the preparation of commercial tunnel diodes for industrial, computer, and microwave applications.[10]

Perhaps the most outstanding RCA Laboratories contribution to the technique of growing epitaxial layers is an arrangement[11] so simple and compact that it can be set up in almost any laboratory. The entire equipment is shown in Fig. 1. The quartz tube in the center contains the substrate wafer, spaced only 10 mils from a source wafer which can be a simple polycrystalline wafer or even a layer of powder. The base wafer and the source layer are held at the required temperatures by the infrared lamps. Only the substrate and the source are heated, instead of the large portion of the reaction system that must be heated in the other methods. The walls are, therefore, cool and the chemical reaction that forms the layer cannot take place at the walls to coat them and so waste expensive material; as a result, over 95% of the source material goes into the grown layer.

The close spacing not only cuts down waste but it also makes the method easy to apply. In other vapor-growth methods, the source is so far from the growing layer that a delicate balance of temperatures and vapor flow rates must be reached if the epitaxial layer is to have the desired composition. With the close spacing, however, ingredients in the proper proportion in the source wafer are automatically present in the proper proportion at the surface, a few mils away, where growth is taking place.

Moreover, the close spacing increases the speed of layer growth. The temperature gradient between the source and the growing layer is roughly 200 times the gradient in wide-spaced systems. This gives strong convection currents in the vapor and a high concentration of the ingredients at the point of growth. Some epitaxial layers that formerly required a day or more to prepare can now be grown in an hour.

The new "close-spaced" method is being used in Somerville and it has been adopted so widely in RCA Laboratories that it has yielded a large portion of the research results described in the next section.

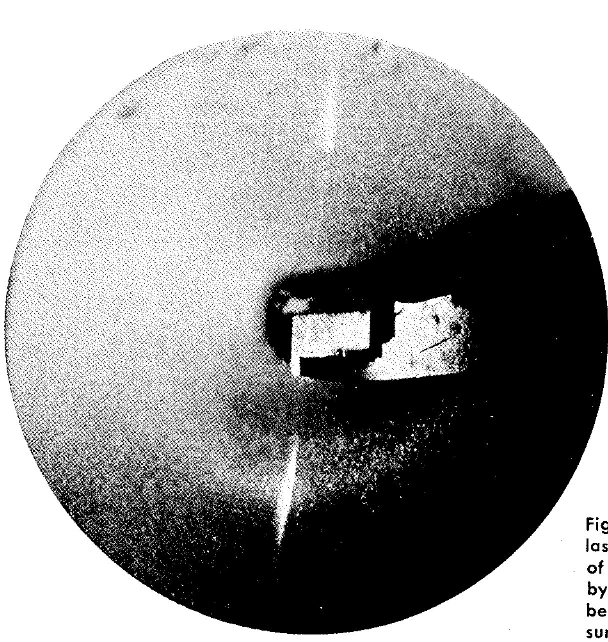


Fig. 3—Narrow infrared laser beams from the ends of a diode laser prepared by epitaxial growth. The beams are striking the surface of a conical metal shield.

DEVICE RESEARCH BY USE OF EPITAXIAL LAYERS

The advantages cited for epitaxial layers are permitting research on many new devices that would have been impractical by conventional construction methods. As an example, it was predicted several years ago that a transistor with the emitter-base junction formed of two *different* materials would have better high-frequency performance than a transistor with the same material on both sides of the junction. Recently, epitaxial growth of gallium arsenide on germanium has given the first operative samples of such a transistor. A section of an epitaxial layer of gallium arsenide on germanium, in this case prepared by the close-spaced method, is shown in Fig. 2. The layer is about a mil thick, uniform, and shows the typical sharp boundary between the epitaxial material and the support.

In an epitaxial layer, the distribution of impurities that control conductivity can be predetermined exactly because the impurities are introduced when the layer is grown. This attribute has provided improved devices, such as Somerville's epitaxial transistors, even when the grown layer and the supporting wafer are of the *same* material. In RCA Laboratories, a junction between an n-type epitaxial layer of gallium arsenide, prepared by growth from a solution on a p-type gallium arsenide base, has given the first samples of our electrically-pumped diode laser capable of continuous-wave operation.[12] The advantage of this type of laser is that the input power comes from the current through the diode rather than from optical pumping by light; as a result, the laser can be modulated by merely modulating the diode current.

Fig. 3 is an unusual picture of narrow laser beams coming from the ends of one of these diode lasers. Since this laser emits in the infrared region of the spectrum, the picture was taken on infrared-sensitive film. Of course, it was necessary to make the beams strike something to reflect light into the camera; in the photograph you are seeing the reflections of the beams from the diffusing surface of a conical metal shield.

Many new devices are being made possible not by the thinness and controllable doping of epitaxial layers, but by the practical consideration that *several highly desirable materials can be grown easily only by epitaxial techniques.* Gallium phosphide and an alloy of gallium phosphide and gallium arsenide are examples. Gallium phosphide has been epitaxially grown on gallium arsenide used as a crystalline support merely to promote the growth of the gallium phosphide. A diffused junction was then formed within the phosphide. The result was our first diode that emits visible light, in this case green, when pumped electrically.

Similarly, an epitaxial layer of gallium-phosphide–gallium-arsenide alloy was prepared on a crystalline gallium arsenide substrate used only to orient the epitaxial growth. After diffusion doping to form a junction in the alloy, visible red emission was obtained. This diode has since been used as a pump to drive a conventional crystal laser. The diode can be electrically modulated, which in turn yields modulation of the crystal laser, whereas an ordinary light source used as an optical pump for the crystal laser would be difficult to modulate. Recently, coherent laser emission has been produced by the red-emitting alloy diode alone.

Zinc selenide, as well, is difficult to grow in single-crystal form, but epitaxial layers of zinc selenide have been prepared successfully on supports of either germanium or gallium arsenide. It is anticipated that high-efficiency electroluminescence will be obtained when current carriers are injected across a junction formed within the zinc selenide.

There is still another class of devices —solar cells—in which epitaxial layers are aiding research.[13] Gallium arsenide solar cells are usually made from a solid crystalline wafer of the material. Since the junction is made close to the surface, most of the costly gallium arsenide is merely a support. Cells have now been made by forming the junction within a thin epitaxial layer of gallium arsenide grown on a supporting wafer or inexpensive germanium. These new cells have already given efficiencies within a factor of two of the efficiencies of cells made of a wafer of gallium arsenide alone. Work has been started on gallium phosphide solar cells, as well. We wish to investigate this material for solar cells because it has the characteristics required for superior performance. Fortunately, single-crystal gallium phosphide can be grown relatively easily by epitaxial techniques whereas it is difficult to prepare by any other method.

CONCLUSION

The epitaxial technique is probably the most significant advance in the semiconductor technology since the introduction of the diffusion method for preparing transistors. The indications are that the range of application of epitaxial layers will increase rapidly, for only a beginning has been made on the use of layers of new materials and on the design of devices with new geometries. RCA is one of the leaders in the epitaxial field.

The information for this review was obtained from the many scientists carrying on the work at the David Sarnoff Research Center. Only a fraction of this activity has been described, with the realization that any attempt to point out highlights is almost certain to overlook work that can become of major importance at any time. Except for the mention of a few projects, it has been impossible to review the outstanding work performed in Somerville. Other aspects of this Somerville work and of the RCA Laboratories effort have been covered in a series of papers in the December 1963 issue of the *RCA Review.*

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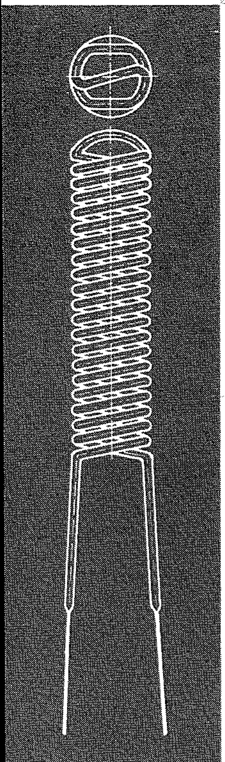
Fig. 1—Left: A typical heater. Below: Section through a conventional "white" heater wire, illustrating how: 1) the alumina is opaque to radiation from the hot tungsten wire; and 2) the alumina conducts heat away from the wire and radiates heat from its surface to the cathode.



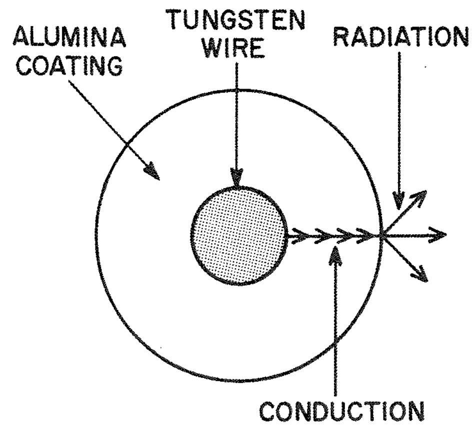
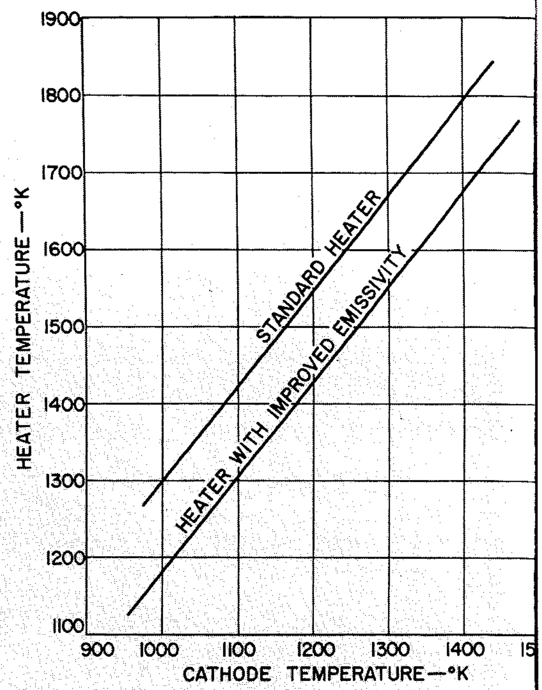


Fig. 2—Heater-cathode temperature characteristics for conventional and improved heaters.



HIGH-EMISSIVITY COATING FOR PICTURE-TUBE HEATERS

This new high-emissivity heater coating improves performance of TV picture tubes. Analysis of the heat-transfer rate between the normal alumina-coated electron-tube heater and the cathode indicates that a significant improvement can be expected if the emissivity of the heater coating is increased. Experimental confirmation of the anticipated improvement has led to the development of a dark, nonconductive heater coating. This coating, initially used for receiving tubes, has been found both beneficial and practical for picture-tube heaters. The advantages of the "dark heater" include improved "sag" characteristics, greater burnout resistance, improved heater-cathode arc-over resistance, and greatly improved reliability due to the lower wire temperature in operation. The important design considerations are discussed with respect to physical geometry and electrical characteristics.

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ROBERT K. SCHNEIDER received the degree of Bachelor of Ceramic Engineering in Glass Technology from Ohio State University in June, 1953. After graduation, he joined RCA in the picture-tube activity of the Electronic Components and Devices organization at Marion, Indiana. He has worked on product and process development engineering for both black-and-white and color picture tubes. Mr. Schneider is a Registered Professional Engineer and is a member of The American Ceramic Society.

In most electron tubes, including picture tubes, the cathode must be heated to a temperature of about 1,000°K to stimulate the electron emission necessary for proper functioning of the tube. This heating is usually accomplished by passage of an electrical current through a metallic tungsten coil placed in close proximity to the cathode but electrically insulated from it.

The insulation (of heater from cathode) has traditionally been accomplished by the application of a coating of sintered aluminum oxide to the tungsten coil. Because this type of coating exhibits relatively poor heat-transfer characteristics, the tungsten wire must be heated to temperature of 1,300 to 1,800°K to attain the cathode temperatures required during tube manufacture and normal operation. These high operating temperatures permit changes in the crystal structure of the tungsten wire, and thus limit the life of the heater.

In addition, continued thermal cycling of the heater from room temperature to the required high operating temperature induces stresses between the coating and the wire, as well as within the wire itself, of sufficient magnitude to weaken the tungsten and to cause extensively distortion and sometimes failure of the heater. It has previously been shown that heater life is exponentially dependent on temperature and that a small

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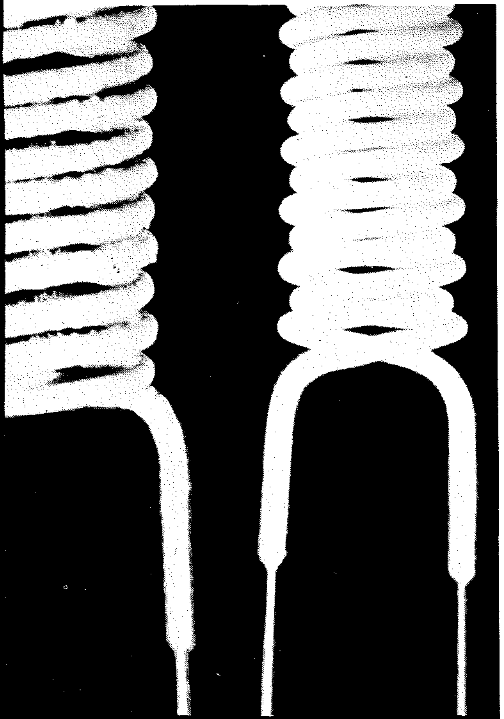
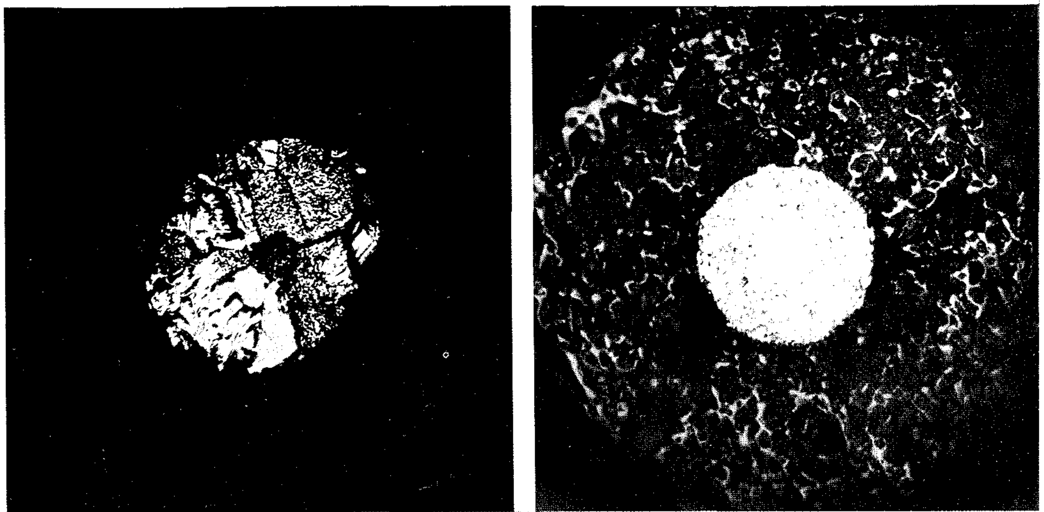


Fig. 3—Conventional and "dark" heater of 6.3-volt, 600-milliampere design.



a) white heater wire   b) dark heater wire

Fig. 4—Cross sections of heaters operated to produce equal cathode temperatures.

decrease in heater temperature can, therefore, greatly extend the life.

HEATER-EMISSIVITY STUDIES

A study of the heat-transfer phenomenon in the indirectly heated cathode system shown in Fig. 1 revealed two basic facts about the conventional alumina heater coating: 1) the coating is largely opaque to radiation at the wavelengths involved, and 2) the heat transfer within the cathode system includes conduction of heat from the bare wire to the coating surface and radiation from the coating surface to the cathode. This study reconfirmed a previously recognized potential for improving the heater-cathode system by application of *black-body radiation* principles.

Basically, a black body may be defined as one which absorbs all the energy which it receives. The radiation from such a body would, therefore, be a function of temperature only. The emissivity of any body is a fraction relating the radiation absorption properties of that body to those of a black body considered to have an emissivity of unity. Tests demonstrated that if the emissivity of the heater coating could be increased, the radiated heat would increase for a given wire temperature. The heater could then be operated at a lower wire temperature and still fulfill the function of raising the cathode temperature to the required value for proper electron emission. Fig. 2 shows the relationship between heater temperature and cathode temperature for the conventional indirectly heated cathode system and for a system utilizing a heater with improved emissivity.

For a given amount of heat energy or power input, the cathode temperature should stabilize at the same value regardless of the emissivity of the heater. However, the heater-wire temperature will vary depending on the means by which this heat energy, or power, is utilized to raise the cathode to the given temperature. With conventional low-emissivity heaters, the heater wire must become very hot to radiate sufficient heat to the cathode to produce a given temperature. Higher-emissivity heaters may consume the same amount of power, but they are able to radiate sufficient heat to the cathode while operating at lower wire temperatures.

DEVELOPMENT OF DARK HEATERS

Most of the materials tested as possible coatings or as additives to the standard alumina heater coating either had too poor an insulative value or outgassed later in tube life, and consequently, affected the cathode electron emission. Recently, however, a suitable "dark coating" and associated application techniques have been developed which provide a high-emissivity heater with good insulative and outgassing properties. This particular coating, initially developed at the RCA Harrison plant for use in receiving tubes[1,2], has since been adapted to other types of electron tubes, including picture tubes. Because the improved emissivity of the new dark coating permits lower wire operating temperature, and thus lower electrical resistance, the diameter of the picture-tube heater wire was reduced by about 10% to maintain the proper voltage-current characteristics.

This new dark coating can be applied by any one of the conventional methods, such as spray coating, drag coating, or cataphoretic coating. In most instances, the dark coating is applied as an overcoat (over the standard white coating) because emissivity is a surface phenomenon.

This new high-emissivity heater is rightly called a *dark heater* because the method of improving the emissivity resulted in a darkening of the coating surface. Fig. 3 shows a conventional heater and a dark heater side-by-side for visual comparison. For all practical purposes, they have the same physical size and are thus interchangeable in present cathode systems.

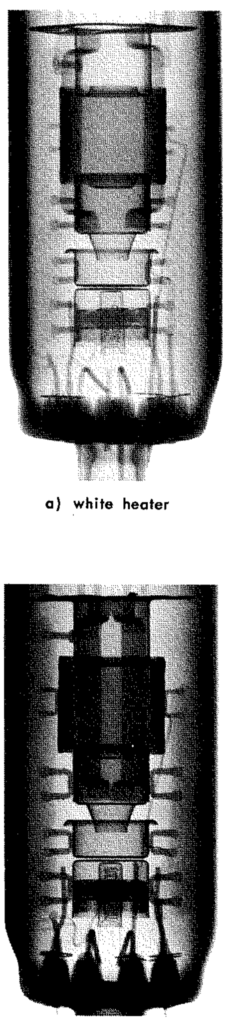
ADVANTAGES OF DARK HEATERS

Experience with dark heaters in television picture tubes has revealed six important advantages of the dark heaters as compared to conventional white heaters:

1) lower wire temperature during operation.

2) improved burnout characteristics.
3) improved mechanical stability with life.
4) reduction in initial surge during warmup.
5) reduction in heater-cathode leakage after long life.
6) improved arc-over resistance.

The first advantage listed above, lower wire temperature during operation, is probably the most significant difference between conventional and dark-coated heaters. Because the strength of tungsten wire is greater at lower temperatures, internal stresses are reduced and the tendency of the wire to recrystallize and fail is minimized. Fig. 4 shows cross sections of marginal-quality heater wires operated to produce the same cathode temperature; larger grain size resulted in the heater employing white coating; fine-grained structure was retained in the dark-coated wire. (Data show that large grain size is associated with heater failure.)



a) white heater

b) dark heater

Fig. 5—X-ray photographs showing "sag" in white and dark heaters after 2000 hours.

The second advantage listed above is improved burnout characteristics. More efficient radiation properties make it possible for the dark-coated heater to handle greater "abnormal" currents than conventional heaters before burnout occurs. As a result, resistance to burnout due to momentary current overloads is improved. Actual wattages at burnout are more than 25% greater for dark heaters than for white heaters.

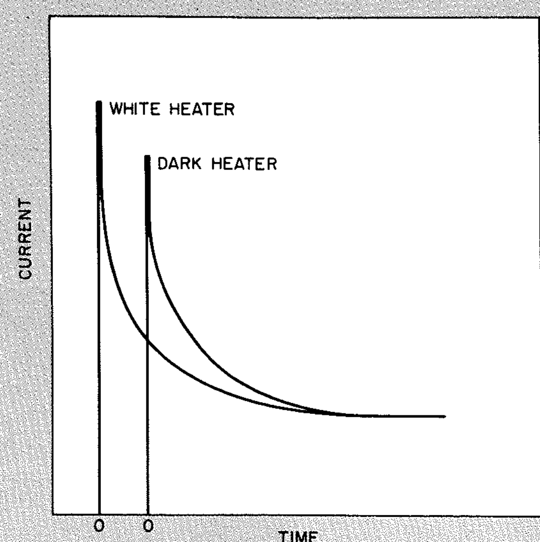
The third advantage is improved mechanical stability with life. Fig. 5, which shows heater sag after 2,000 hours of tube operation, demonstrates the improved mechanical stability of the dark heater. The cooler operation of the dark heater minimizes the typical changes in heater shape during life, and thus yields a more constant cathode temperature and a reduced probability of heater-cathode shorts.

The fourth advantage, reduction in initial current surge during warmup, is evident from the curves shown in Fig. 6. Initial current surge during warmup is reduced by 15% when dark heaters are used because there is less change from hot to cold resistance. This lower surge results in less wear and tear on the heater wire during *on-off* cycling throughout life.

The fifth advantage is a reduction in heater-cathode leakage after long life. The significantly lower heater-cathode leakages of dark heater systems after long life may be the result of less migration of conductive metallic ions from either the heater wire or the cathode material into the coating; such migration effectively reduces the resistance of the coating in conventional heaters after prolonged operation.

The last advantage listed is improved arc-over resistance. Because dark heater coating increases heater-cathode arc-over resistance considerably, it provides a greater margin of safety in heater-to-cathode operating voltage ratings and also minimizes heater damage in the event of an inter-element arc within the electron gun.

Fig. 6—Comparison of initial current surge during warmup in white and dark heaters.



SUMMARY

The advent of the dark-heater concept presented an opportunity for engineering and quality improvement in picture-tube designs, even though heater failures had not represented a significant field consideration in RCA product for several years. After engineering tests which verified the potential for increased safety factor (or quality reserve), this additional performance feature is being introduced into the RCA picture-tube product line.

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The application of presently available UHF transistors in the oscillator stage of a UHF tuner results in improved tuner performance. In comparison with a vacuum tube, the major advantage is longer life. The selection of the transistor is based mainly on its output power capability at the highest operating frequency. A substantial improvement of oscillator frequency stability is obtained from decoupling of the transistor from the resonant tank. This paper presents two types of oscillator circuits with various decoupling methods, along with their frequency stability performance. The design of a quarter- and half-wavelength resonant tank is developed analytically and the results presented in a graphical form. The results of the study of transistors and circuits were applied to a practical design. An RCA UHF tuner was modified to operate with the RCA TA-2401 transistor for use in both black-and-white and color TV receivers. A satisfactorily stable tuner performance was obtained; frequency drift resulting from a 10% change of the line voltage is less than 100 kc over the entire 420-Mc tuning range, representing about 0.01% change.

DESIGN OF UHF TRANSISTOR OSCILLATORS

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The design of a UHF transistor oscillator requires an understanding of the high-frequency large-signal operation of transistors and a knowledge of UHF circuits. A local oscillator in a UHF tuner must satisfy several conditions—such as adequate power output, reasonable lifetime, and good frequency stability. In addition, cost and simplicity of construction suitable for mass production are also important.

Several UHF transistors in various oscillator circuits were studied; in particular, the RCA TA-2401 proved suitable for the intended application and offers the following advantages when compared with vacuum tubes: longer life, improved frequency stability, lower oscillator radiation, and reduced power consumption. The UHF circuitry such as that employed with vacuum tubes can be utilized; several possible variations are presented. The final design consisted of the RCA TA-2401 coupled capacitively to the $\lambda/2$ resonant oscillator tank. Only minor mechanical modifications of the KRK-66 tuner were required. While no degradation of any tuner characteristics was experienced, the frequency stability was improved and the drift resulting from a $\pm$ 10% change of the supply voltage was less than $\pm$ 100 kc.

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SELECTION OF TRANSISTORS

The characteristics of some commercially available UHF transistors are given in Table I. Since transistor operation in an oscillator circuit is nonlinear and the signal is relatively large, small signal parameters are less useful and the most important criteria are the maximum frequency of oscillation f_{max} and the amount of available power at a specified frequency. For the UHF application, f_{max} should be above 1 Gc; approximately 5 mw of available power is required. Although only 0.5 mw of power is utilized in the mixer diode, the reserve is needed to maintain sufficient decoupling from the oscillator circuit. Since output power in a transistor oscillator diminishes with increasing frequency, the minimum output should be checked at the highest frequency of operation.

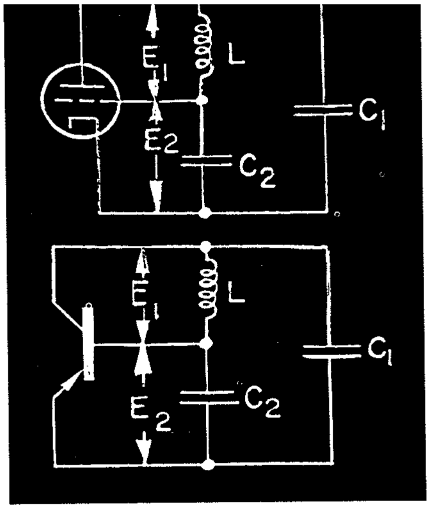


Fig. 1—Vacuum tube and transistor colpitts type oscillators: $E_2/E_1 = C_1/C_2$, for $C_2 >> C_1$.

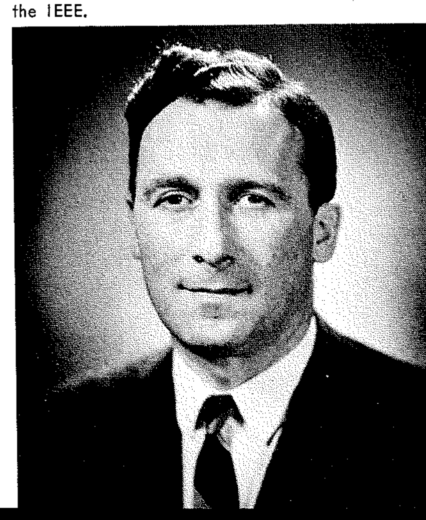
The choice between silicon or germanium transistors is determined mainly by the ambient temperature of the receiver; silicon units have a definite advantage when operating at higher temperatures.

Most UHF transistors are mounted in the T018 case, and some are housed in a plastic bead. (The effect of shell capacitance on feedback is analyzed later.) The transistor evaluations included the TA-2401 and other types; each transistor was applied to various oscillator circuits and evaluated with respect to power output and frequency stability. Several types of transistors were found suitable for the oscillator application; however, the improved high-frequency performance of the TA-2401 resulted in better frequency stability.

TABLE I — UHF Transistors

Transistor	Type	Case	f_{max} (Gc)	Power Output
TA-2401 (RCA)	silicon planar	T018	2	8 mw at 900 Mc
SE3001 (Fairchild)	silicon double diff. planar	plastic	1.5	6 mw at 930 Mc
TIX316 (Texas Inst.)	germanium mesa	T018	2	5 mw at 1,000 Mc
AF-139 (Siemens)	germanium mesa	T018	2	5 mw at 1,000 Mc
T2872 (Philco)	germanium micro alloy	T018	—	2 mw at 900 Mc

L. A. HARWOOD graduated from Munich Institute of Technology in 1949 with a BSEE. He received his MSEE in 1959 from the University of Pennsylvania. Following engineering experience at Pilot Radio Corp. and Picattiny Arsenal, Mr. Harwood joined RCA in 1952 as an engineer in the Home Instruments Division; his experience in television receivers includes work in development and design of UHF and VHF tuners, development of parametric and tunnel diode converters, and development of a transistorized UHF tuner for TV receivers. Now located with the Home Instruments Division in Somerville, he had most recently been a member of the Home Instruments Affiliated Research Labs., Princeton, N. J. He has been granted several patents in his field of work; he is a member of the IEEE.



OPERATION OF THE TRANSISTOR OSCILLATOR

The analysis of the transistor oscillator is covered extensively in literature. High-frequency harmonic oscillators are generally the Colpitts type, and circuits of transistor and vacuum-tube oscillators are quite similar (Fig. 1).

As a first approximation, the frequency of oscillation is determined by the circuit and the device reactance. The feedback voltage is determined by the capacitive divider C_1, and C_2, while the proper phase is secured by the series combination of the inductor L and capacitor C_2. At UHF, the feedback capacitance is usually provided by the device and shell capacitance; application of external feedback is difficult because of lead inductance.

Depending on the circuit and shell connections, capacitance can either reduce or increase the amount of feedback. The three networks are shown in Fig. 2. Transistor parameters are both temperature and voltage sensitive; oscillator frequency stability may be greatly affected by a change of either one. Although for small variations of operating conditions, the effects may be second order; however, such effects may not be tolerated in a TV receiver where good frequency stability is of utmost importance.

An equivalent circuit of a transistor is shown in Fig. 3. For completeness, the parasitic lead inductances and the shell capacitances are also included, since at UHF they represent a large percentage of the device reactance. The circuit is the π-equivalent transistor representation usually employed for small-signal analysis; in an oscillator circuit, the various elements may have values different from those measured at low signal levels. In normal operation, the emitter-to-base junction is forward biased, and a reverse bias is applied between collector-to-base terminals. The uncompensated stored charges in the collector-to-base junction give rise to the transition capacitance, which is a function of the applied voltage and is given by:

$$C = \frac{K}{\sqrt[3]{V_{cb}}} \qquad (1)$$

Where: V_{cb} is the operating collector-to-base voltage.

In an oscillator circuit, the RF signal between the collector and base can exceed several volts, so that the transition capacitance varies at the rate of the oscillator frequency similarly to a varactor diode energized by a large pump signal. Under these conditions the effective capacitance which can be obtained from a Fourier analysis will differ from values obtained from Eq. 1.

The extremes of the voltage swing are determined by the transistor characteristic, bias point, and the mode of operation. The instantaneous output conductance also varies, depending on the magnitude of the signal strength, and the conductance increases while the transistor is driven into saturation and becomes very small beyond the cutoff point. The effective transconductance is a function of the transistor characteristic and the waveform and amplitude of the oscillator signal.

The effect of the diffusion capacitance C_D on the frequency stability is not immediately obvious. This capacitance, which is originated by the flow of minority carriers in the base region, is proportional to emitter current:

$$C = \frac{qW_o^2}{K2D_p} I_e (1 - KV^n) \qquad (2)$$

Since the flow of minorities requires a charge-density gradient, variation of the current by a changing applied voltage requires a redistribution of the charge densities. A change of charge with voltage corresponds to an incremental capacitance. The transition capacitance associated with the emitter-to-base junction is much smaller than the diffusion capacitance and can be neglected. The diffusion capacitance is usually represented by a lumped capacitance in the emitter-to-base junction and in a Colpitts oscillator shown in Fig. 1 it appears across the tank inductance in series with the collector-to-emitter feedback capacitance.

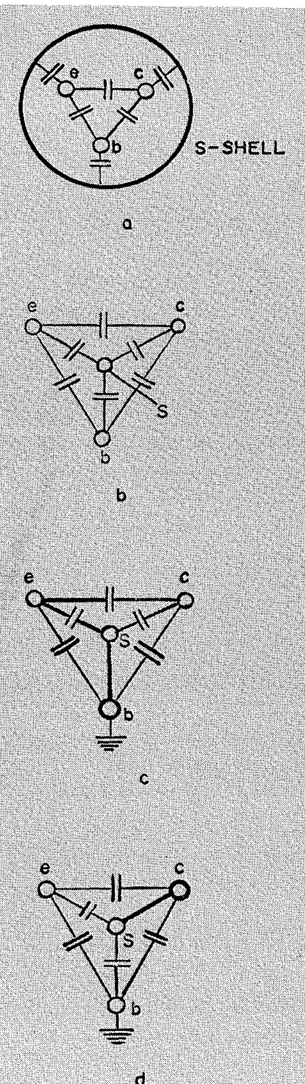


Fig. 2—The case capacitance effect on the oscillator feedback; a) and b) are equivalent representations of the case capacitance; c) case connected to the base-feedback reduced; and d) case connected to the collector feedback increased.

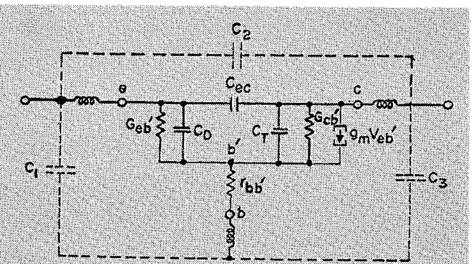


Fig. 3—Equivalent circuit of a transistor.

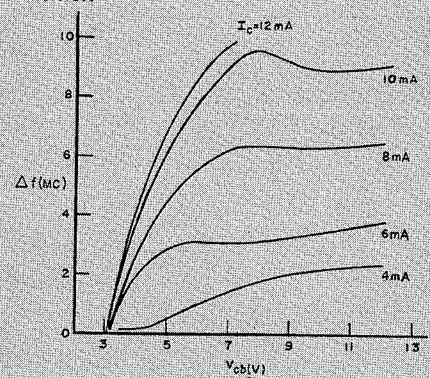


Fig. 4—Frequency drift with varying collector voltage transistor TA-2401.

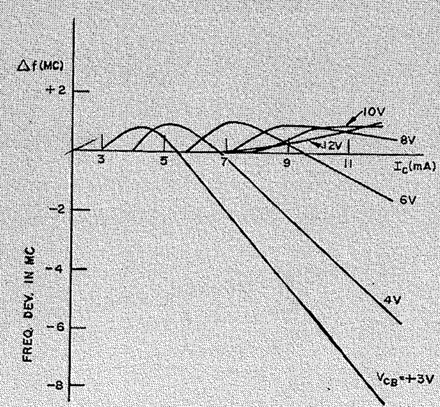


Fig. 5—Frequency drift with varying collector current transistor TA-2401.

Experimental data on frequency stability are shown in Fig. 4 and Fig. 5. The measurements were taken on a UHF oscillator with the transistor operated at either a constant V_{cb} voltage and with variable emitter current or constant emitter current and variable collector voltage. For small capacitance changes the frequency variation is proportional to the capacitance change; hence, the plots should reveal the nature of the variable parameters.

For relatively small collector voltages and large collector currents, there is a certain degree of correlation with this analysis. With constant collector voltages the frequency drift is proportional to the collector current which agrees with Eq. 2. The slope of those lines depends on the collector potential, since the diffusion capacitance is a function of the base width which varies with collector-to-base voltage. The curves in Figs. 4a and 5a deviate from the $1/\sqrt[3]{V_{cb}}$ characteristic and for small collector currents can be approximated by the $1/V_{cb}$ expression.

Without further study of the transistor as an oscillator, the curves in Figs. 4 and 5 do not reveal the exact mechanism of the frequency drift. The plots are useful, however, in choosing the point of operation. Since a change of the supply voltage results in a change of the collector voltage and current, it is possible to select a region in the two families of curves where cancellation takes place and the frequency change is a minimum. In a simplified analysis, it can be assumed that the collector voltage and current each suffer the same percentage change as the power supply. This simplifies the selection of the bias, and the cancellation corresponds to a point where the ratio of the tangents of curves in Figs. 4 and 5 is inversely proportional to the negative ratio of the respective voltage and current values. The selected point has to comply with the required oscillator power and DC dissipation.

In practice, the improvement of the frequency stability by this method was inadequate. Although cancellation at some frequencies was experienced, this was not sufficiently reproducible with various transistors and could not be maintained over the entire tuning range.

A major improvement in oscillator stability was obtained by decoupling the transistor from the resonant tank. The various decoupling methods and the effects on stability are discussed in the following section.

UHF OSCILLATOR CIRCUITS

In general, UHF circuits can be classified as *lumped* or *distributed;* the distinction is determined entirely by the dimensions. Thus, a transmission line, shorted at one end, is equivalent to an inductor provided the relationship $L < \lambda/12$ is satisfied. (For an angle less than $\pi/6$, the tangent of the angle is equal to the angle with an error of less than 10%.)

Because the Q factor of lumped circuits at UHF is relatively poor, it is common practice to employ resonant lines. For a large frequency range (such as the television UHF band), a given line length may be considered as a lumped element at the lowest frequency, while transmission-line equations are necessary at higher frequencies. In designing an oscillator circuit with a variable capacitor as the tuning element, it is necessary to determine the capacitance range required for a given frequency range. Two types of circuits are considered, the $\lambda/4$ and $\lambda/2$ resonant-line oscillator circuits (Fig. 6).

The $\lambda/4$ Oscillator Circuit

In this circuit, the transmission line is shorted at one end, while the transistor and the tuning capacitor are connected in parallel at the other end of the line. The ratio of the total minimum-to-maximum capacitance ratio for a 2:1 frequency ratio can be computed as shown below. The results are plotted in Fig. 7. This ratio increases for diminishing line lengths and approaches the value of 0.25. As expected, this limit is identical with lumped-circuit considerations.

The frequency stability obtained with this oscillator is shown in Fig. 8. The stability is poorer with increasing frequency, since with less tuning capacitance, the transistor parameters have a larger effect on the frequency of oscillation. The frequency stability can be improved by either inductive or capacitive decoupling of the transistor from the resonant current (Fig. 9).

A quarter-wave resonant circuit is shown in Fig. 10. It consists of a transmission line loaded with a variable capacitor. Let C_1 and C_2 be the capacitance values corresponding to the resonant frequencies f_1 and f_2; then:

$$\frac{X_1}{Z_o} = \tan\frac{2\pi L}{\lambda_1} \qquad (3a)$$

And:

$$\frac{X_2}{Z_o} = \tan\frac{2\pi L}{\lambda_2} \qquad (3b)$$

For a 2:1 frequency ratio (500 to 1,000 Mc), we obtain $\omega_2 = 2\omega_1$, and:

$$\frac{C_2}{C_1} = \frac{\tan\frac{\omega_1 L}{c}}{\tan 2\omega_1 L} = \frac{1}{2}\left(1 - \tan^2\frac{\omega_1 L}{c}\right) \qquad (4)$$

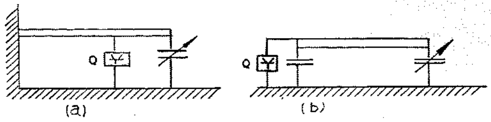


Fig. 6—Simplified circuits a) the $\lambda/4$ and b) the $\lambda/2$.

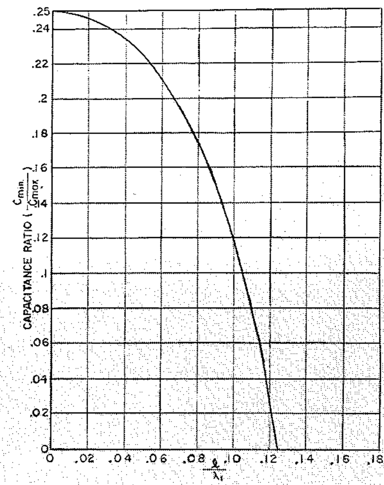


Fig. 7—Capacitance ratio required for a 2:1 frequency tuning range with a $\lambda/4$ resonant line.

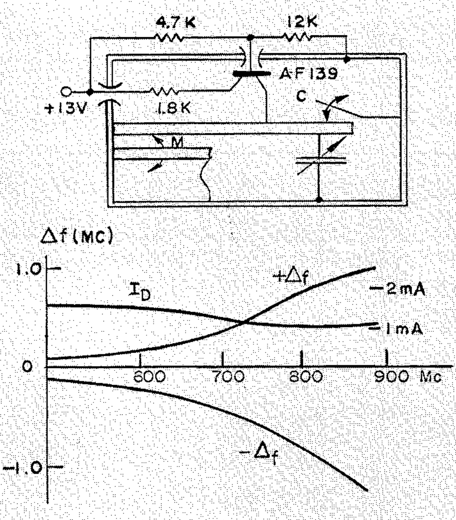


Fig. 8—The $\lambda/4$ UHF oscillator and its drift characteristic (for ± 10% supply variation; diode current vs. frequency).

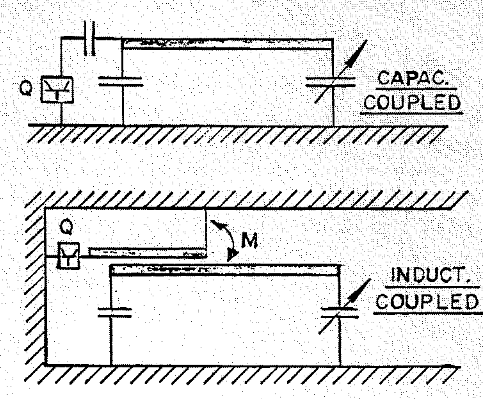


Fig. 9—Two $\lambda/4$ oscillator circuits.

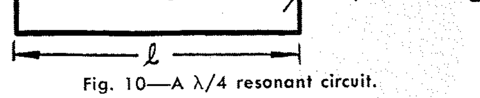


Fig. 10—A $\lambda/4$ resonant circuit.

Where: c = propagation velocity. Eq. 4, which is plotted in Fig. 7, gives the required capacitance ratio for a 2:1 frequency ratio and a given line length L. The actual value of C_1 and C_2 is given by:

$$C_1 = \frac{1}{\omega_1} Z_o \tan\frac{\omega_1 L}{c} \qquad (5)$$

And:

$$C_2 = \frac{1}{\omega_2} Z_o \tan\frac{\omega_2 L}{c} \qquad (6)$$

The λ/2 Oscillator Circuit

An oscillator using the λ/2 resonant circuit of Fig. 11 is shown in Fig. 12. The tuning capacitance and the transistor are at opposite ends of the transmission line, and the transistor being shunted by the capacitor C_S. The analysis of this circuit follows from the existence of a neutral point on the line, whose position is determined by the terminating capacitances. At resonance, this point divides the line into two circuits resonant to the same frequency. The capacitance range required to tune a prescribed frequency range is a function of the line length, its characteristic impedance, and the value of the terminating capacitance C_T (including the device capacitance). The capacitance ratio for a 2:1 frequency ratio is plotted in Fig. 13 with the line length as a parameter and the ratio of the terminating reactance to the characteristic impedance as the independent variable.

The frequency stability for a λ/2 oscillator is shown in Fig. 12. It is almost constant over the entire tuning range, as expected for this type of circuit. Since the terminating capacitor shunts the transistor, large values of terminating capacitance will result in improved frequency stability. Capacitive and inductive coupling methods are shown in Fig. 14, and the improved frequency stability with capacitive coupling is plotted in Fig. 15. The degree of improvement is a function of the capacitive coupling, as shown in Fig. 16.

For the λ/2 resonant circuit in Fig. 11, we also assume a 2:1 frequency ratio (500-1,000 Mc) and the tuning capacitances C_1 and C_2 at one end of the line correspond to the resonant frequencies f_1 and f_2, respectively. Capacitance C_T terminates the other end of the line (and includes the device capacitance).

The capacitance ratio for a 2:1 frequency ratio is given by the following expression and is plotted in Fig. 15:

$$\frac{C_2}{C_1} = \frac{1}{2}\,\frac{\left(\tan\frac{\omega_1 L}{c} - m_1\right)}{\left(1 + m_1\tan\frac{\omega_1 L}{c}\right)} \cdot \frac{\left(1 + \frac{1}{2} m_1 \tan^2\frac{\omega_1 L}{c}\right)}{\left(\tan^2\frac{\omega_1 L}{c} - \frac{1}{2} m_1\right)} \qquad (7)$$

Where: $m_1 = \tan(\omega_1 d_1/c)$, and $m_2 = \tan(\omega_2 d_2/c)$.

As can be seen, the capacitance ratio increases with diminishing m_1 values for line lengths shorter than approximately 6 cm. Above this value, the capacitance ratio has an optimum value which is evident from the curves for the 7-cm and 7.3-cm line lengths; however, the physical realization of this ratio may not be possible. It appears that for practical reasons, the line length should remain within 3-to-6-cm limits. Although a short line permits a relatively high C_2/C_1 ratio (small C_{max}/C_{min} ratio) the wiping contacts on the tuning shaft become more critical and may have to be eliminated by a different design approach (capacitive return). The agreement of the computed curves with practical results will depend on many factors such as discontinuities of the line (characteristic impedance), the effective length of the capacitor plates, the effect of the shaft inductance, and the device lead inductance. An example will illustrate the design procedure of the λ/2 resonant circuit.

For a 500-to-1,000-Mc tunable oscillator, we choose a line length of 4 cm and assume a variable capacitor with a capacitance ratio $C_{max}/C_{min} = 10$; then, $C_2/C_1 = 1/10$, and the m_1 value from Fig. 13 is 0.25. If the characteristic impedance of the line is selected as 100 ohms, then the value of the terminating capacitor C_T is equal to approximately 12.8 pf, and the value of C_1 is equal to 19 pf; consequently, the required tuning range is 1.9 to 19 pf.

Inductively Coupled λ/2 Oscillator Circuit

A UHF oscillator with the transistor coupled inductively to the λ/2 resonant circuit and its equivalent circuit is given in Fig. 17. The condition for oscillation requires that at the transistor terminals the total admittance be zero. From the equivalent circuit in Fig. 17, we obtain:

$$Z_{in} = j\omega L_1\left[1 - \frac{k^2}{1 - \left(\frac{\omega_2}{\omega}\right)^2}\right] \qquad (8)$$

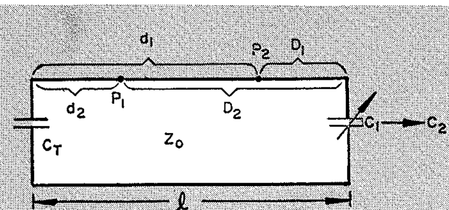


Fig. 11 — A λ/2 resonant circuit.

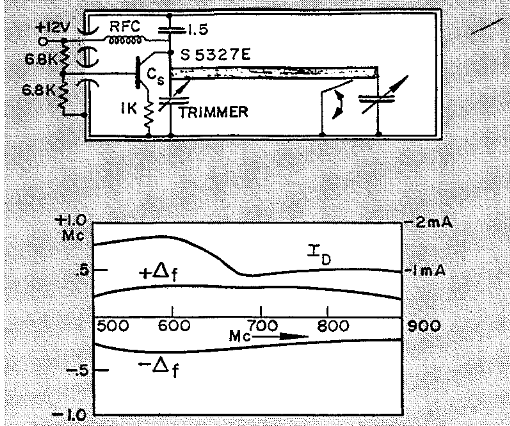


Fig. 12—The λ/2 UHF oscillator and its drift characteristic (for ± 10% supply variation; diode current vs. frequency.).

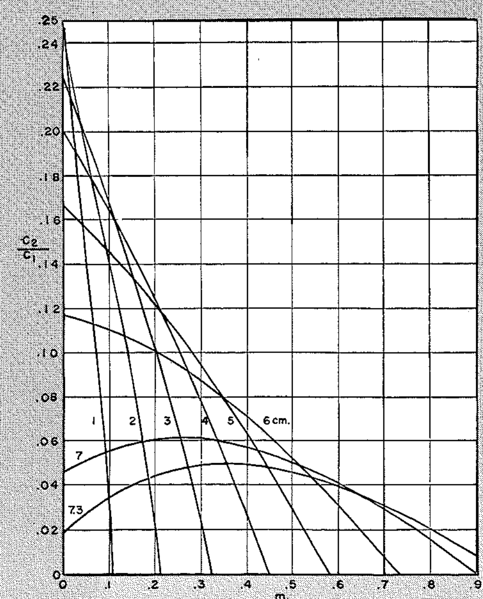


Fig. 13—Capacitance ratio for λ/2 resonant line, 500-to-1,000-Mc tuning range.

Eq. 8 is the impedance of the tuned circuit, coupled inductively to the transistor. The total admittance, including the device capacitance, will reduce to zero for $\omega C_1 = 1/Z_{in}$, or:

$$\left(\frac{\omega}{\omega_1}\right)^2 \left(1 - k^2 \frac{\omega^2}{\omega^2 - \omega_2^{\,2}}\right) = 1 \quad (9)$$

The solution of Eq. 9 gives two frequencies for which oscillations are possible. By proper choice of circuit parameters, the resonance at the higher frequency (Fig. 17) can be placed at ω'', where the transistor is not capable of supporting oscillation. Since this oscillator circuit is basically that of a double-tuned circuit with one resonance fixed, the coupling from the transistor to the variable circuit diminishes at lower frequencies. This is compensated by the fact that the transconductance of the transistor increases for decreasing frequencies and the power output remains relatively constant over a large tuning range.

KRK-66 TRANSISTOR OSCILLATOR

The KRK-66 tuner was modified to operate with a transistor oscillator. The circuit is shown in Fig. 18. The vacuum tube originally employed is replaced with the RCA TA-2401 transistor. The newly developed transistor oscillator provides adequate power, and the injection current in the mixer diode remains between 1 to 2 mamp, with relatively loose coupling of the diode to the oscillator circuit. The original tuning characteristic (tracking), noise figure and other tuner characteristics also remain unchanged. The frequency drift due to a 10% change of the supply voltage is less than 100 kc over the entire tuning range (Fig. 15).

The results of the study of transistors and circuits presented in the previous sections of this paper were applied in the design of this transistor oscillator. The selection of the biasing point was based on Figs. 5 and 6, and the choice of the coupling capacitor was determined from Fig. 16. Although the frequency stability improves with diminishing values of the coupling capacitor, measured at 600 Mc, the best compromise with regard to frequency stability and reliable operation over the entire tuning range was obtained with a 2.2-pf value of capacitance.

The KRK-66 tuning capacitor was preserved by maintaining the original oscillator line (center conductor) and by increasing the value of the terminating capacitor at the end of the line. This compensated for the removed vacuum tube capacitance.

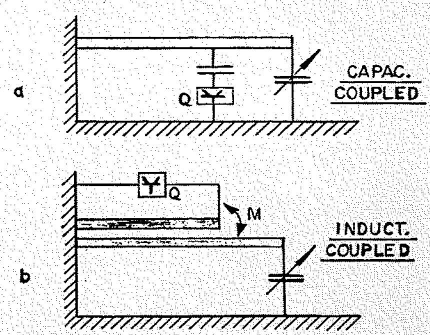


Fig. 14—A λ/2 UHF oscillator with a) capacitive, and b) inductive decoupling.

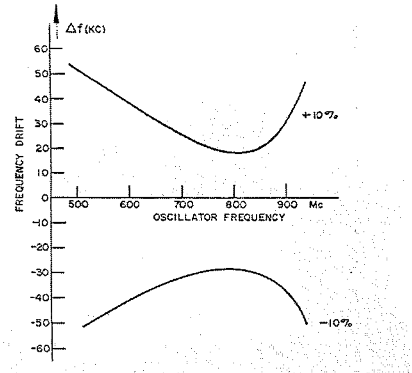


Fig. 15—Frequency drift for a ±10% change of supply voltage with the TA-2401 transistor coupled to the resonant circuit by means of a 2.2-pf capacitor.

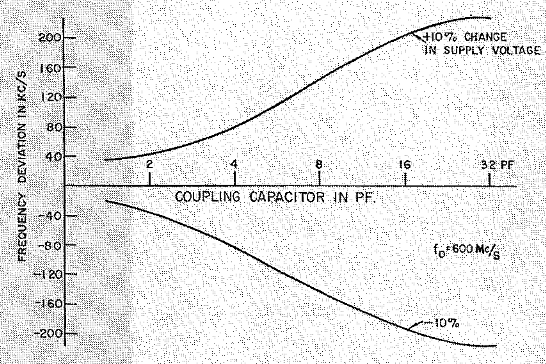


Fig. 16—Effect of capacitive decoupling on frequency stability.

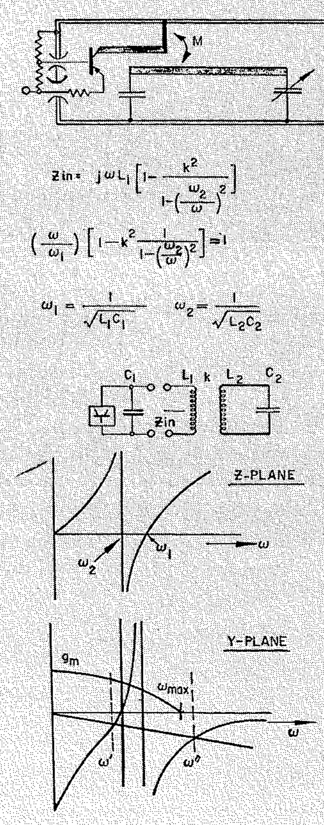


Fig. 17—The λ/2 UHF oscillator with inductive coupling.

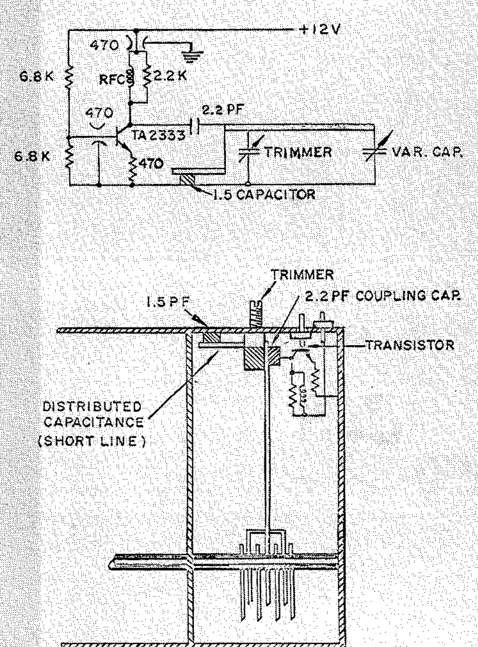


Fig. 18—KRK-66 modified transistor oscillator.

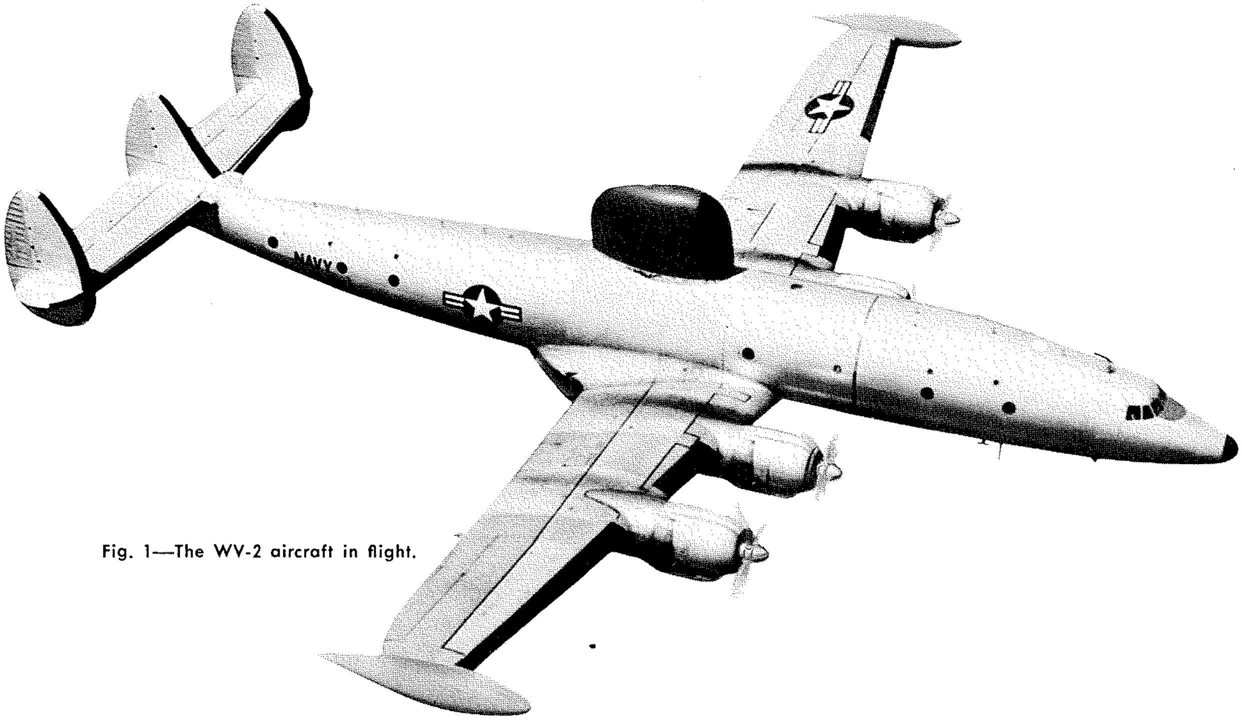


Fig. 1—The WV-2 aircraft in flight.

AN AIRBORNE FOUR-FREQUENCY, FREQUENCY-STABILIZED COHERENT RADAR SYSTEM

A four-frequency radar serves as a general-purpose airborne-research tool for studying target characteristics and background clutter. Technical features provided: 1) a 20:1 frequency range, 2) phase coherent system, 3) measurement of complete polarization matrix, 4) built-in calibration, 5) tape recording of data, 6) antenna pointing from horizontal to straight down, 7) excellent range accuracy, and 8) double recording gates for target and clutter. The system has 40 different gated (recordable) output signals. The first uses of this airborne radar are for measuring the complete polarization matrix of ships, sea clutter, and terrain clutter. The radar serves as one terminal for study of echoes bistatically (transmitter and receiver not co-located), and as one terminal in a tropospheric propagation experiment; the aircraft is equipped to measure meteorological parameters (refractive index, temperature, pressure and humidity).

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The four-frequency radar equipment consists of seventeen six-foot relay type racks specially designed for airborne use, plus two oversize transmitter cabinets and three operator consoles containing displays and controls (Figs. 1, 2, 3). Radar antenna arrays are housed in a composite unit within a radome mounted on the underside of a modified WV-2 naval aircraft (military Superconstellation). The radar mechanical design includes pull-out drawers for maximum access to equipment.

OPERATING PARAMETERS

The four-frequency radar system (Fig. 4) consists of four different pulsed coherent radars having (respectively) the following transmitting frequencies: P band (428 Mc); L-band (1,225 Mc); C-band (4,455 Mc); and X-band (8,910 Mc). Each of the four radars is designed to operate with two antennas either separately or pulsed alternately;

Final manuscript received September 16, 1963

* Since this paper was completed, Mr. McCall has transferred to the DEP Missile and Surface Radar Division, Moorestown, N. J.

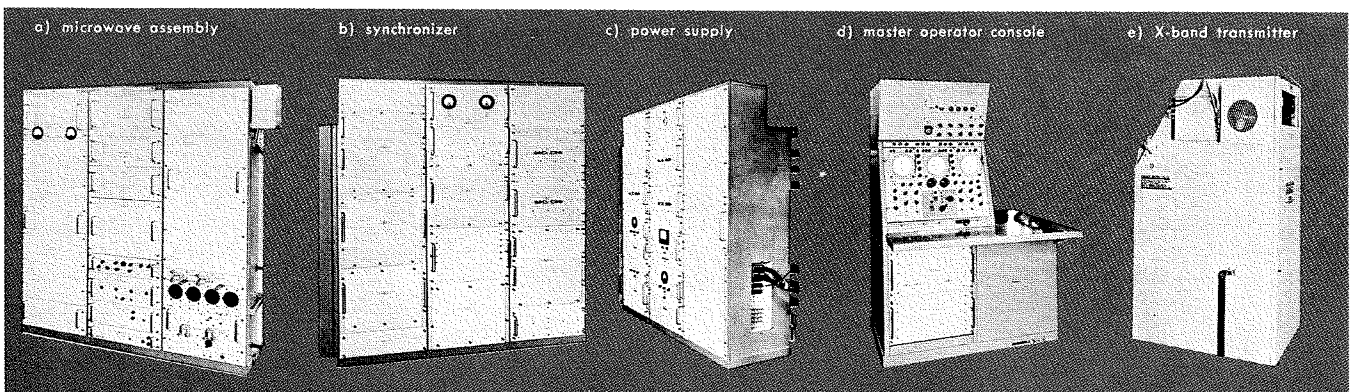


Fig. 2—Basic equipment group for the four-frequency radar equipment.

one antenna is polarized horizontally and one vertically.

The four frequencies can be transmitted singly or in rapid succession to provide a total of eight different vertically and horizontally polarized transmissions for subsequent target data correlation. Fig. 5 depicts the rapid transmission mode. Multiplexed among the four frequencies are two pairs of IF receiver polarization channels (one horizontal, and one vertical). Each polarization channel contains a linear-logarithmic (lin-log) amplifier and a limiting amplifier to provide simultaneous horizontal- and vertical-polarization amplitude and phase target-information.

A temperature-controlled 1.15-Mc crystal oscillator serves as a stable signal source; frequency multipliers produce outputs at 37 Mc, 391 Mc, 1,188 Mc, 4,418 Mc and 8,947 Mc. Except for the 37-Mc output, each one serves as input to a frequency translator and as local-oscillator input to each microwave crystal mixer in the receiver. The frequency translators mix the inputs with a gated 37-Mc input to provide the pulsed signal at the desired output microwave frequency. The 37-Mc input to the translator is gated to the desired pulse width in the IF modulator by a pulse from the synchronizer. Each driver and final amplifier combination increases the power level to the desired output level without significantly changing pulse shape, timing, frequency, or phase characteristics. The final amplifier is *pulsed on* to prevent the amplification of noise during the *transmitter-off* time.

Each radar antenna is controlled by a synchronizer that switches the transmitter output pulses alternately between the duplexer systems of the (two) horizontal and vertical antennas associated with that band. Received signals at the two antennas are passed through the respective duplexers to the two receiver microwave mixers and IF preamplifier units. Both the antenna and target cross-polarization characteristics cause a signal to be received in each antenna regardless of which antenna transmits a pulse; however, there should be a difference in signal amplitude. Outputs from the two IF preamplifiers, one for vertical and one for horizontal signals, are centered at 37 Mc. The outputs are passed through a pair of bandwidth filters to a corresponding pair of IF amplifiers. Signals passing through the lin-log IF amplifiers are detected to provide horizontal and vertical channel video output pulses which are linear in voltage amplitude for voltage inputs increasing exponentially. The limiting IF amplifiers provide a constant-amplitude IF output signal for any level of IF input voltage; such limited output signals serve as inputs to the phase comparators which provide relative-phase video output signals; an additional coherent input signal is required from the 37-Mc stable signal source as a reference.

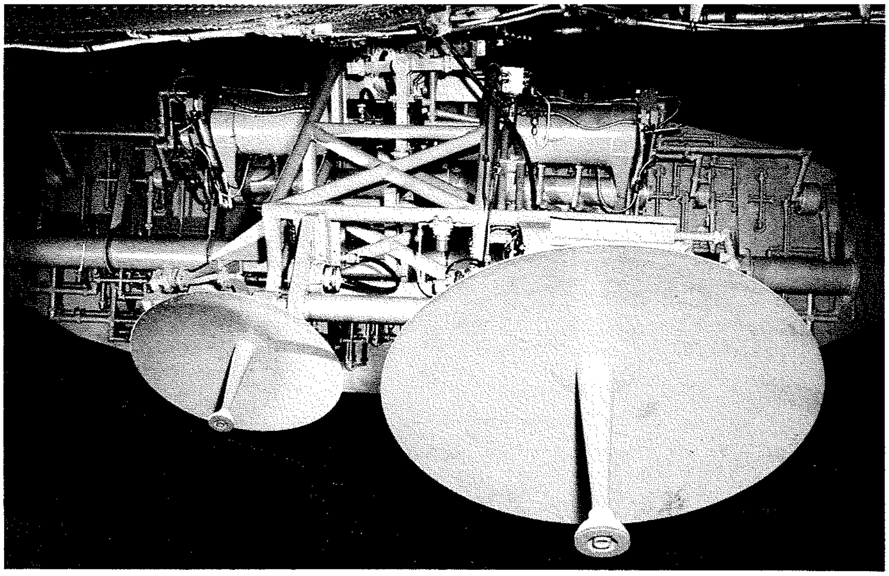


Fig. 3a—Antenna arrays installed on the underside of the WV-2 aircraft.

The three relative-phase outputs are: 1) received vertical signal versus the 37-Mc reference, 2) received horizontal signal versus the 37-Mc reference, and 3) received vertical signal versus the received horizontal signal. The five types of video signals, three phase and two amplitude, are then given the proper scale factors to drive the displays and the recorder. The synchronizer maintains the proper timing relationships between functions. An operator, while watching the displays, can fine-tune the system for the particular operating conditions. Tables I, II, and III summarize the principal radar system operating parameters and indicate the diversity of operation available from the system.

THE SYNCHRONIZER AND RANGING UNIT

The synchronizer-and-ranging unit provides timing and synchronization for the rest of the radar, i.e., it supplies modulator triggering pulses, video-pulse driving signals, indicator sweep-start triggering pulses and timing-mark signals. It also provides a main range-gate which can be set rapidly and precisely with an accuracy of several yards at any range out to 200 miles; an auxiliary second range-gate can be positioned with respect to the first so that a target can be examined in time as it passes through the two gates. Digital readout to the nearest yard is provided for the main range gate.

The heart of the AN/FPS-16 type equipment is a precision resolver whose phase shift or equivalent time delay is an extremely accurate function of the mechanical rotation of the resolver rotor. The accurate 82-kc reference frequency and counters furnish synchronization and timing voltages. Table II indicates the large number of independent radar parameter adjustments furnished by this timing unit—such as pulse repetition rates, pulse widths, range-gate widths, range-mark spacings and widths. Receiver bandwidth can be set independently of pulse width.

Fig. 3b—Another view of the antenna arrays installed on the underside of the WV-2 aircraft.

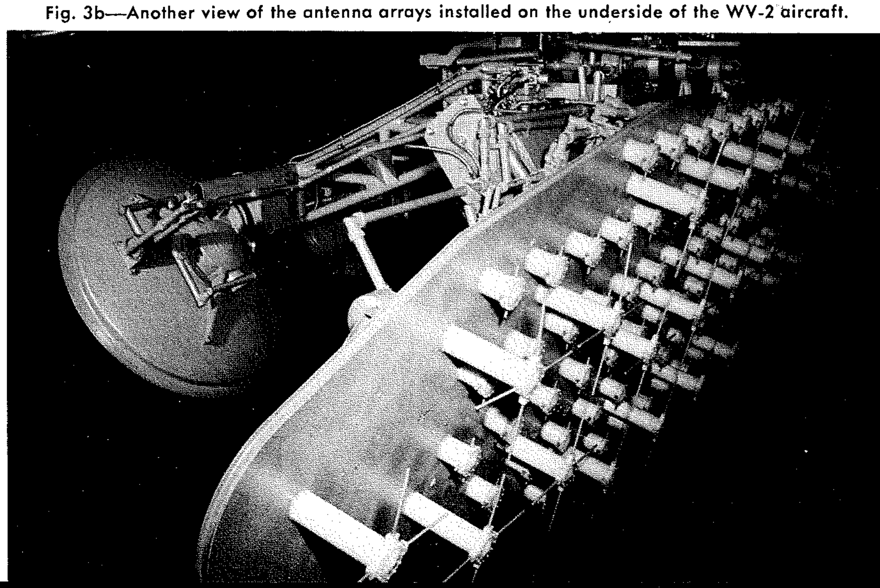


TABLE I—Principal Parameters of Four-Frequency Radar System—Transmitters

Parameter	*428 Mc*	*1,225 Mc*	*4,455 Mc*	*8,910 Mc*
Long Term Frequency Stability—No Greater than	1 part in 10^6 per day	1 part in 10^6 per day	1 part in 10^6 per day	1 part in 10^6 per day
Short Term Frequency Stability (0.01 sec)	Within 5 parts in 10^9-10^8	Within 5 parts in 10^9-10^8	Within 5 parts in 10^9-10^8	Within 5 parts in 10^9-10^8
Peak Power, kw	35-40	35-40	25	40
Average Power, watts	140	140	100	160
Peak Power, Special Mode, watts	10	10	10	10
Interpulse Phase Stability—No Greater than:	4°	4°	5°	6°
Output Tube	7651 tetrode (RCA)	7651 tetrode (RCA)	SAC—290 Klystron (Sperry)	V24C Klystron (Varian)

TABLE II—Principal Parameters of Four-Frequency Radar System—Signal and Display Parameters

Repetition Rates	Submultiples of 81.959 kc: 100.45, 200.90, 301.35, 394.07, 512.30, 602.71, 683.07, 788.16, 1463, 2926 cps.
Pulse Widths, μsec	0.1, 0.25, 0.5, 1, 2
Noise Figure, db	9-11 including all RF losses
IF Amplifier:	
Center Frequency, Mc	37
Bandwidth, Mc	10, 4, 2, 1, 0.5
Type	lin-log, 25 and 50 db dynamic range, and limiting.
Quantity	Two pair: one for horizontally polarized signals one for vertically polarized signals.
Range Gate:	
Width, μsec	0.1, 0.2, 0.5, 1, 3, 5
Increment Readout, yd.	1
Range Marks:	
Width, μsec	1.0, 2.0, 5.0, 20
Spacing, Naut. miles	1, 5, 20
Video Systems:	
Consoles	Total 3: 2 operators and 1 master control
Displays	Dual-beam A scope, B scope and PPI for each console. All flat face tubes.
CRT Size	5 inches
Signal Outputs (ungated and gated)	Vertical polarization signal amplitude. Horizontal polarization signal amplitude. Vertical/horizontal polarization phase. Horizontal polarization/transmitted signal phase. Vertical polarization/transmitted signal phase.
Maximum Video Amplitude	2 volts, peak-positive

TABLE III—Project SUSPENDER Antenna System Performance

Frequency Polarization	*P-Band*		*L-Band*		*C-Band*		*X-Band*	
	Horiz.	*Vert.*	*Horiz.*	*Vert.*	*Horiz.*	*Vert.*	*Horiz.*	*Vert.*
Bandwidth, Mc	±5	±5	±5	±5	±10	±10	±10	±10
Azimuth Beamwidth	12.3°	12.1°	5.5°	5.5°	5°	5°	5°	4.7°
Elevation Beamwidth	40°	41°	13.8°	13°	5°	5°	5.3°	5.0°
Azimuth Minor Lobe, db	14.5	14.5	13.4	14	23.2	23.0	23.6	23.6
Elevation Minor Lobe, db	30	26	16	14	24.5	24	23.5	24.2
Cross Polarization, db	25	28	25	25	>20	>20	>20	>20
Transmission Line Loss, db	0.6	0.3	0.6	0.8	2.0	2.0	0.6	0.6
Antenna Gain, db	17.4	17.4	25.9	26.2	31.4	31.4	31.2	31.2
Voltage Standing Wave Ratio	<1.44:1	<1.38:1	<1.35:1	<1.28:1	<1.50	<1.57	<1.30:1	<1.12:1
High Power	OK	OK	OK	OK	Not Measured		OK	OK

CONSOLES AND CONTROLS

There are four places in the system where continuing control functions take place: the master operator console, the two secondary consoles, and the microwave rack. All video signals are available for independent monitoring at the three consoles; signals are presented on A-scopes, PPI, and B-scopes. All consoles include both gated and continuous video signals. Target ranging and antenna pointing can be transferred between the master console and subconsole 1; tape recording controls exist only at subconsole 2. Radar pulse length, receiver bandwidth, and the second range gate are controlled exclusively from the master console. Display features include a 10-Mc video bandwidth, range read-out digitized to 1 yard, range sweeps from 1/4 to 200 miles in length both normal and delayed, and dual-trace A-scope display with independent selection of video.

At the microwave rack, continuous video only is presented on an A-scope. Transmitter monitoring, receiver calibrations (phase and amplitude), and antenna VSWR measurement controls are located only at the microwave rack.

ANTENNA

The four-frequency antenna can be described more exactly as being four antennas with pairs of arrays back-to-back on a common mount. The two lower-frequency arrays are crossed dipoles on a common ground-plane. The two higher-frequency arrays have separate parabolas facing 180° away from the dipole arrays (Fig. 2). The antennas turn through 315° of azimuth, 100° of elevation, and are stabilized in roll and pitch. Antennas can sector-scan in azimuth and elevation at 30°/sec. Antennas are located in a radome on the underside of the WV-2 aircraft. The radome is of tapered honeycomb construction with a maximum thickness of 1.268 inches. The overall transmission coefficient (all angles and polarization) is 80% at X-band and 87% at C-band. In general, vertically polarized transmission results in less loss than does horizontally polarized transmission. Electrical characteristics of the antennas are given in Table III.

STABLE SIGNAL SOURCE

The stable signal source furnishes five high-quality CW signal outputs. One output serves as the IF (37-Mc) phase comparator reference voltage and drives the IF modulators which provide the basic system RF pulses at 37 Mc. The other four output signals, each at a level of 30 mw, are used to translate these 37-Mc pulses to microwave pulses at 428 Mc, 1,225 Mc, 4,455 Mc, and 8,910 Mc. Except for the 1.15-Mc precision oven-controlled Manson basic oscillator, all of the signal amplification and frequency multiplication is provided by transistors and semiconductor capacitor diodes (varactors). The advantages of the solid-state design over thermionic devices are longer life, significant heat reduction, realization of better tuned-circuit stability, freedom from microphonic and thermionic noise, and relatively simple circuits. The primary problem is to achieve a spectrum purity which establishes short-term frequency stability and minimizes system phase error. It is important to start with a signal-to-noise ratio as large as possible in the early stages of multiplication; selection of the basic crystal oscillator in the 1-to-5-Mc region takes advantage of the large Q of crystals in this frequency range. Parasitic oscillations must be eliminated during alignment of the unit; noise sidebands must be reduced by shielding and decoupling against crosstalk. Short-term frequency stability between 5 parts in 10^8 and 2 parts in 10^9 has been measured using a stalo stability tester. For a time interval of 1 msec (and all target return times of interest to this program fall within this interval), the contribution of this amount of frequency instability to overall system phase error is less than a degree—even assuming the worst case of frequency change with time, i.e., a step function. The long-term frequency change lies within 1 part in 10^6 per day and does not adversely affect system performance.

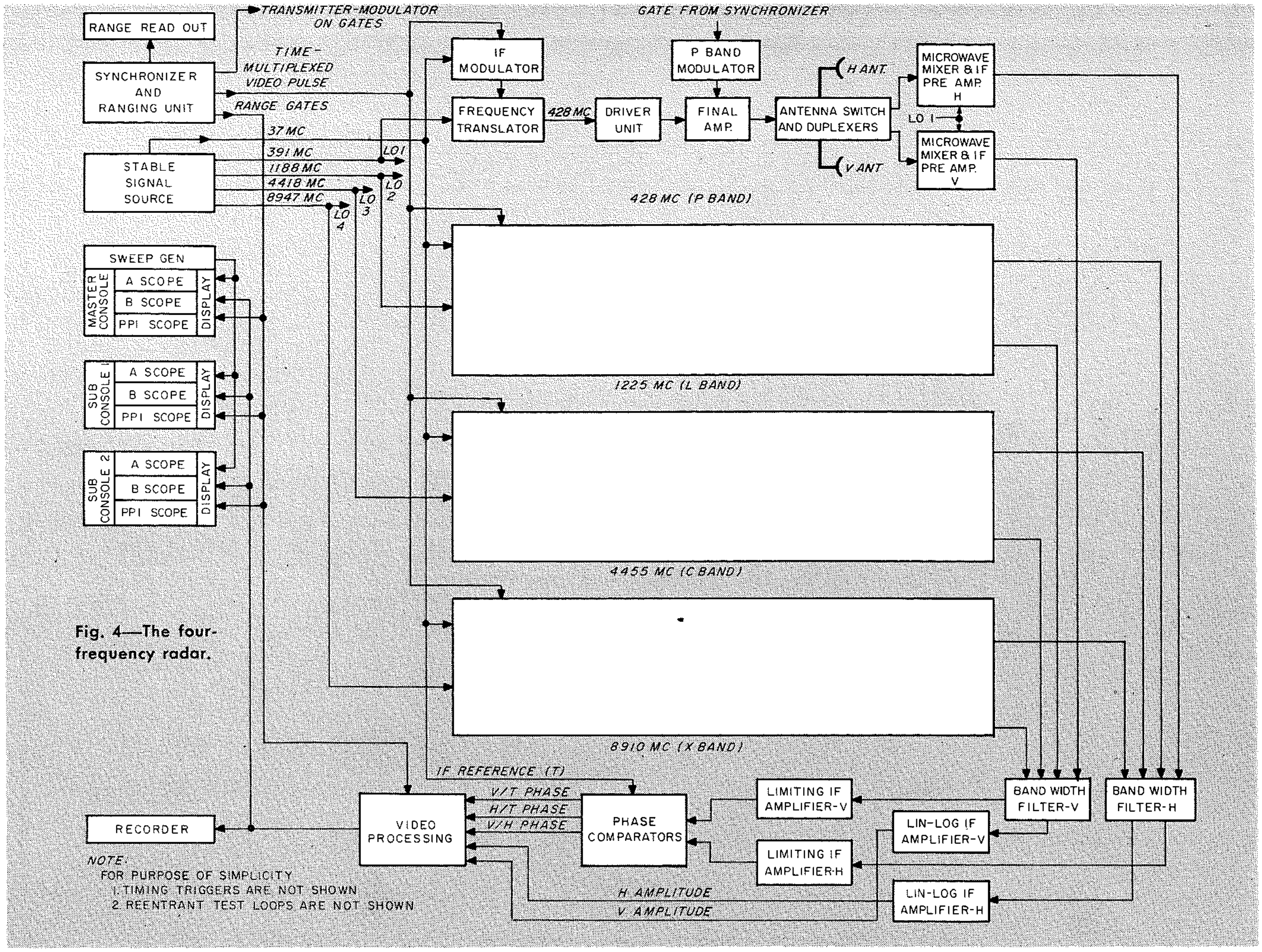


Fig. 4—The four-frequency radar.

TRANSMITTER

The four transmitter chains amplify the shaped RF pulse from the milliwatt level to 25 to 50 kw. Tetrodes are used in external coaxial cavities at P and L bands and one or two TWT's (RF-pulsed) are used to drive the klystron power amplifiers at C and X bands. The principal considerations at X band were: 1) minimizing phase variations through the chains, 2) transmitting RF pulses ranging from 0.1 to 2.0 μsec, at PRF's from 200 to 6,000 pps—limited in combination only by the duty cycle of the RF power amplifier, and 3) obtaining a 1-μsec fall time on the —32-kv klystron pulse to assure rapid receiver recovery. Because of the varying pulse widths and PRF's, a hard-tube modulator was used. To reduce overall stray capacitance, the storage capacitor was returned to ground, resulting in a floating modulator deck at —32kv; a special polycarbonate housing insulates the modulator deck, distributes the electric fields uniformly and minimizes the effects of corona. Tube type power supplies for the transmitters employ a regulating loop consisting of high-gain, chopper-stabilized amplifiers and a mercury battery as a reference.

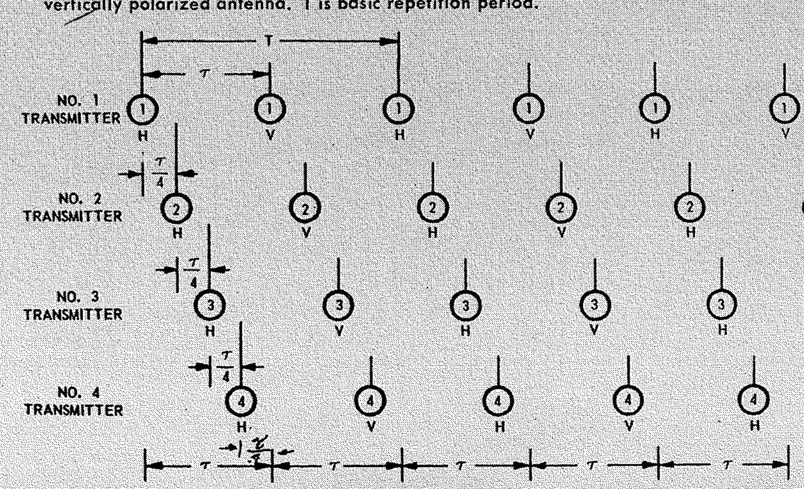
Excellent long-term stability was obtained with regulation on the —32-kv supply in the order of 0.1% and about 0.05% on the TWT supply. Interpulse phase shift as low as 3° peak-to-peak has been measured in the X-band transmitter chain. Fall times of less than 1-μsec were achieved with a dump circuit using a step-down transformer and a hydrogen thyratron. Side effects of this dumping circuit include protection for the klystron in case of a "switch-tube" short by saturating the dumping transformer. In addition to the normal protective circuits, over- and under-voltage protection are included to prevent beam defocussing and burn-out of the TWT helix in case of unusual power supply failures.

The modulator design for the C-band transmitter is basically the same. At P and L band, the design is different due to the positive voltages involved and the bandwidth limitations of the coaxial cavities. To obtain adequate bandwidth, the driver stages are operated with longer pulses, mostly CW, and the output stage is pulsed with high-current oxide-coated cathode switch tubes providing fast rise-time and wide bandwidth.

MICROWAVE UNIT—RE-ENTRANT TEST

The microwave unit (Fig. 6) for each radar includes a frequency translator,

Fig. 5—Transmitter firing order where: transmitter No. 1 is 428 Mc, No. 2 is 8,910 Mc, No. 3 is 1,225 Mc, and No. 4 is 4,455 Mc. The points designated by H indicate excitation of horizontally polarized antenna. Points indicated by V indicate excitation of the vertically polarized antenna. T is basic repetition period.



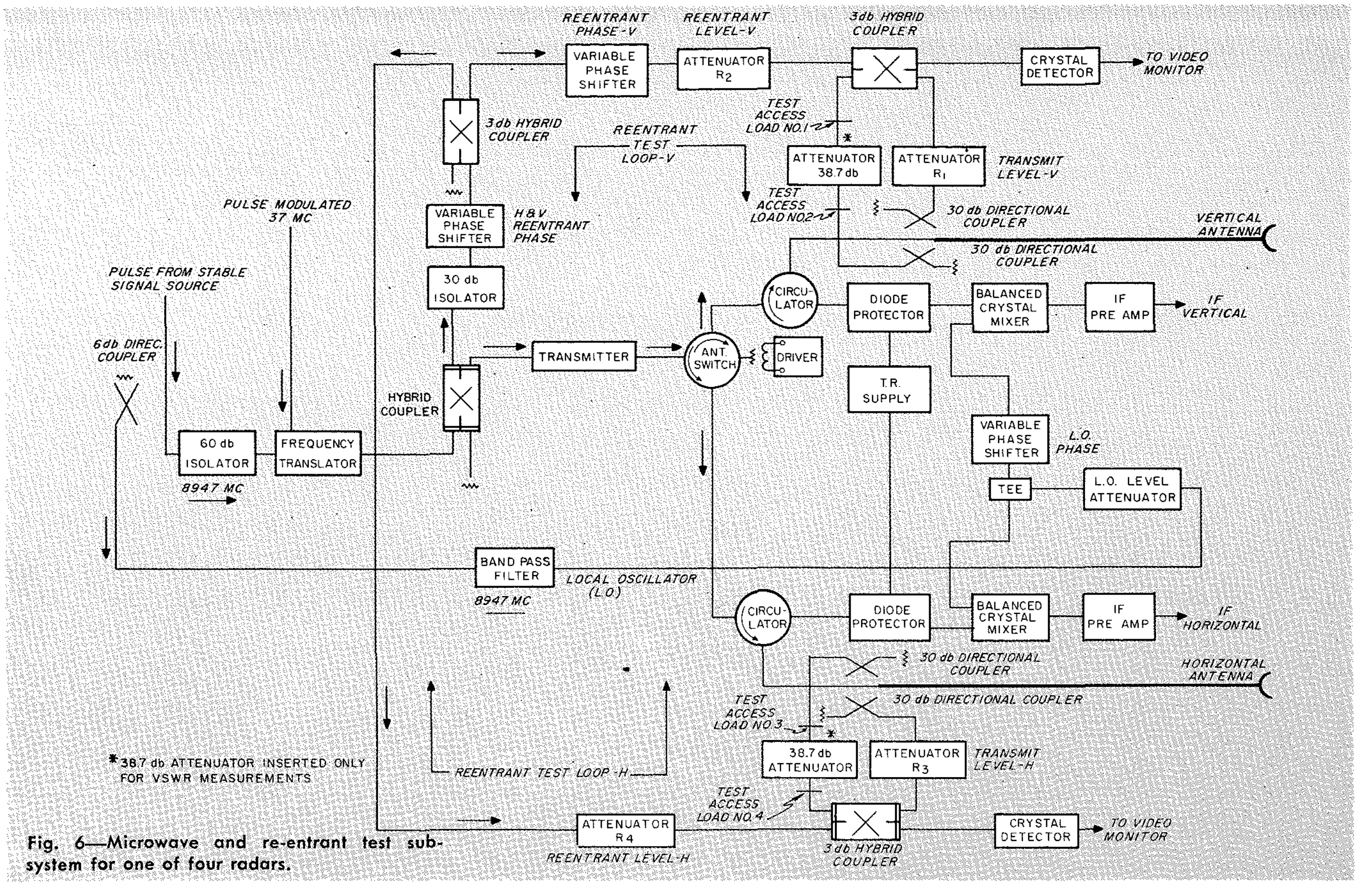


Fig. 6—Microwave and re-entrant test subsystem for one of four radars.

duplexers, receiver front ends, antenna switch and driver, and re-entrant test units.

The frequency translator which introduces negligible phase error, consists of a hybrid-tee balanced crystal mixer with a bandpass filter, and operates at a CW microwave input level of +13 dbm; conversion loss is 11 db, bandwidth (3 db) is 55 Mc, carrier and image suppression are 35 db and 25 db, respectively (measured with respect to signal output). The IF drive inputs at the frequency translator are specially choked to obtain at least 55-db suppression of the microwave signals and prevent microwave pickup at any other position in the system.

Each duplexer consists of a TR tube and a ferrite circulator; TR tube recovery time is approximately 1 μsec. The antenna switch is a solid-state (ferrite) single-pole, double-throw device having approximately −27-db crosstalk isolation. Adjustments are provided in the driver unit to optimize the crosstalk separately for each switch position. The antenna switch requires 450 μsec to change from one polarization to the other, and this is accomplished entirely within the interpulse period; phase error is on the order of 1°.

The re-entrant test loops are waveguide assemblies through which portions of the microwave translator output may be injected into either of the two receiver front ends (independently) for system monitoring, tests, and calibration before and during airborne data runs. The following functions are provided: re-entrant level measurement, minimum discernable signal, amplitude detector dynamic range, ratio of transmitted-to-received power, peak-power measurement, VSWR, calibration of phase comparators, TR recovery time, and phase balance of horizontal and vertical signal channels.

IF COMPONENTS AND PHASE COMPARATORS

Each of the eight IF preamplifers has a conventional Wallman cascode input circuit followed by a buffer tube and a beam deflection tube switch to time share the common horizontal and vertical IF receiving channels. The buffer tube and beam deflection tube are gated *on* at approximately one microsecond following the transmitted RF pulse to prevent overloading of the following IF stages in the bandwidth filters, lin-log amplifiers, and limiting amplifiers; approximately 65-db isolation is obtained during the *off* condition.

The lin-log IF amplifier, conventional in principle[1], has a linear output and logarithmic input relationship which is achieved by successive detection from each of the 6688 tube amplifying stages, and by proper addition of the video in a common load. The special features of the amplifier include an IF bandwidth of 12 Mc, a lin-log transfer characteristic linear within 0.5 db over 45-db dynamic range; performance independent of overall radar duty-cycle variations of 600:1 is obtained by preventing the variation of individual tube bias with input-voltage duty-cycle changes.

Conventional limiting IF amplifier designs for large ranges of input voltage amplitude variation develop appreciable errors in signal phase with signal amplitude changes; when these devices are loaded down to swamp out the phase error, little or no amplification remains. The Z-2800 beam deflection tube makes possible a limiting IF amplifier having output amplitude and phase shift independent of input-signal amplitude variations. The Z-2800 accomplishes this task because of its excellent limiting, constant input and output impedance characteristics, and insignificant input-output coupling. Because the gain bandwidth product of the Z-2800 tube is only 40 Mc, the 7788 high gain pentode was inserted between limiting stages; thus, adequately wide bandwidth was obtained in each Z-2800 stage and a linear gain in the 7788 stages.

Overall push-pull operation further optimized the design. Results of measurements were 70 db of dynamic range with excellent limiting (a small fraction of a db amplitude variation), phase stability within ±2.5° with 60 db of input amplitude change, and 10-Mc bandwidth. The phase stability measurement was made with the phase comparator developed during this program and attenuation networks calibrated for phase and loss characteristics.

Each of the three phase comparators consists of two linear phase detectors and one cosine phase detector; such a combination provides an output amplitude which is linear and unambiguous for a variation in phase from 0° to 360°. The second linear phase detector has its diodes reversed to have an output which is 180° out of phase with the first; each has an ambiguity at 180° intervals. However, when a cosine detector, shifted in phase by 90°, is used as a polarity sensing device controlling a switch, only the positive-slope region of each linear phase detector need be added to obtain a positive-going voltage without ambiguity between 0° and 360°. There is a finite flyback time in returning from 360° to 0°, and a departure from linearity in the vicinity of 180° due to switching. The cosine phase detector is chosen rather than another linear detector since the cosine waveshape has a greater rate of change as the output passes through zero; moreover, the cosine waveshape is greatly amplified to form a gating square-wave signal that drives the deflection electrodes of switch tubes (type 7360 beam deflection tubes). Balanced circuits and low tube capacitances serve to obtain fast switching speed. Satisfactory performance was obtained operating with input signals having pulse widths between 2 μsec and 0.1 μsec, and pulse repetition rates between 200 and 6,000 pps. The output response of 0 to 2 volts for phase changes of from 0° to 360° was linear within 10°, and retrace loss in returning to 0° from 360° was approximately 24°.

VIDEO GATING AND DISTRIBUTION

The video processor receives five types of detected phase and amplitude radar echo (or reentrant test) signals and two range gates; signals are processed and redistributed within the system in ungated and gated form.

RECORDING

A 16-head, 1-inch magnetic-tape system is used for data recording; for three years, it has proven a reliable airborne instrument. The maximum data rate recordable is 25,600 seven-bit binary words/sec. All input data are gated video. There are sixteen input lines with four signals being acceptable simultaneously. These four inputs are stored, serially converted to digital form in 270 μsec, and then four more are accepted. In addition to these high-rate signals, ten other slowly varying parameters can be digitized and recorded once per second. These channels are used for such variables as range, altitude, and temperature; a simplified block diagram appears in Fig. 7. The limitation of only four simultaneous signals needs to be corrected because there are ten nearly simultaneous signals from the radar (2 amplitudes and 3 phases at 2 ranges). The present system is also limited to pulses that are longer than 0.25 μsec but has been used with an auxiliary pulse-stretcher to record 0.02-μsec pulses.

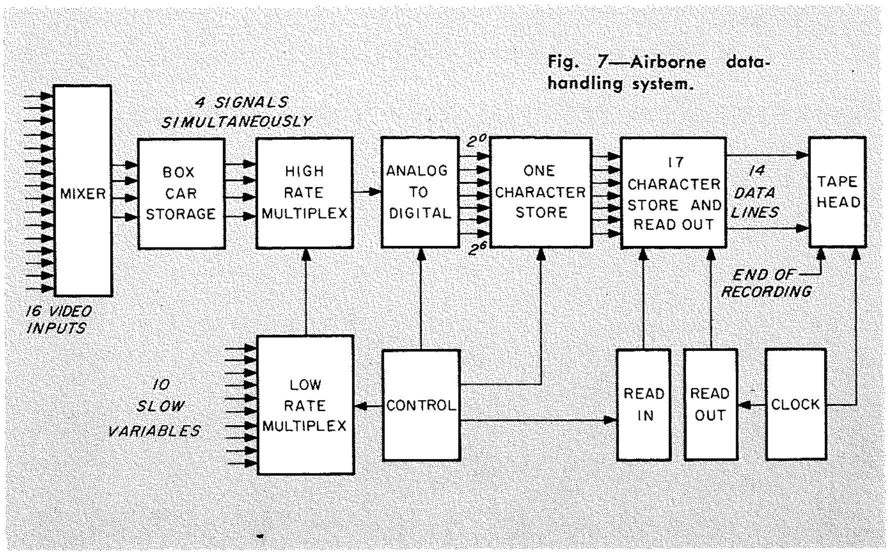


Fig. 7—Airborne data-handling system.

ACKNOWLEDGEMENTS

The work described herein was sponsored by RCA, and under Contract Nonr-3419(00)(X) with the Office of Naval Research and the Naval Research Laboratory (NRL). The Naval Research Laboratory made technical contributions to this program and to this paper; the work of NRL's Frank C. Macdonald and John T. Ransone, Jr. is particularly acknowledged. The authors wish to express gratitude to their fellow engineers at RCA who worked on this program with dedication and enthusiasm. Space does not permit individual recognition, and the group is now divided among various departments in Burlington, Mass., Camden, and Moorestown, New Jersey. At the time of this project all were members of the Airborne Reconnaissance and Surveillance Section within the Aerospace Communications and Controls Division.

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NORMAN G. HAMM graduated with a BEEE from Tulane University in 1943 and a MSEE from the University of Pennsylvania in 1951. From 1943-1945 Mr. Hamm was a Staff Member at MIT's Radiation Laboratory engaged in radar development. He joined the Philco Corp. in Philadelphia in 1945 and until 1957 was employed in the Research Division in a wide variety of radar development, design, and management tasks. In 1957 he transferred to the Radio Corporation of America, Camden, N.J., where he has managed the development and design of airborne fire-control and counter-measures receiving equipment. Mr. Hamm was the design manager responsible for the Four-Frequency, Frequency-Stabilized Coherent Radar System work in RCA's Aerospace Communications and Controls Division in Camden, N.J. and Burlington, Mass. He is presently manager in charge of system integration and test for the LEM radar program at Burlington, Mass. He is a senior member of the IEEE and a member of Tau Beta Pi.

EUGENE G. McCALL graduated with a BSEE from Clemson College in 1948 and a MSEE from the University of Pennsylvania in 1963. During 1945 and 1946 Mr. McCall received training in the U.S. Navy Electronic Schools. From 1948-1952 he designed and developed broadcast transmitters at RCA, Camden, N.J. From 1952-1954 he performed similar tasks at A. B. DuMont Labs., Inc., Passaic, N.J. In the period 1954-1955, Mr. McCall was a Project Engineer at Air Associates, Inc., Orange, N.J., responsible for completing design and testing of a Navy data link communications transmitter. Mr. McCall returned to RCA in 1955 and worked on systems evaluation and development of airborne fire control radar and military TV equipment. He was a leader responsible for systems integration and test of the Four-Frequency, Frequency-Stabilized Coherent Radar System within RCA's Aerospace Communications and Controls Division in Camden, N.J. Mr. McCall is presently systems engineer with RCA's Missile and Surface Radar Division in Moorestown, N.J. He is a member of the IEEE and a member of Tau Beta Pi.

DATATELEX

. . . A New High Speed Transmission Service For International Data Exchange

R. K. ANDRES

RCA Communications, Inc., New York City, N.Y.

A NEW data transmission service for the exchange of all forms of binary data has been inaugurated over the transatlantic cable facilities of RCA Communications, Inc.; prior to this service, the exchange of data over international networks was confined to relatively slow-speed, punch card transmissions over conventional channels designed primarily for telegraph purposes. Such service, offered to a number of countries in Europe and the Pacific, was confined to 5, 6, or 7 fully-punched, 80-column cards per minute corresponding to the conventional standard telegraph speeds of 60, 75, and 100 words per minute. Soon after higher-speed transmission facilities were available throughout the United States domestic networks, wider-bandwidth international channels, similar to those used for radiophoto and facsimile service, were made available for higher-speed data transmission. When the first transatlantic telephone cables were laid, the possibility of utilizing complete voice channels (approximately 300 to 3,000 cps) was considered for a high speed international data transmission service. Extensive tests were conducted by RCA Communications, Inc. to determine the expected performance and error rates of long-haul data transmission over these facilities.

The present service, *Datatelex*, is the outgrowth of these studies and provides for the first time a high-quality, commercial data transmission service capable of exchanging binary-coded data at rates up to and including 1,200 bits per second. Service is now available between New York and London with international circuits to other points planned for the future.

HOW DATATELEX WORKS

Datatelex is an on-line, real-time data exchange service permitting the customer to place a call through the RCA Communications, Inc. New York operator to a particular customer serviced by the General Post Office central office in London. When the international operators have established the connection, the two subscribers commence exchanging data. At present, the customer provides his own high-speed data transmission equipment for transmitting punch cards, perforated tape, or magnetic tape in any code or format at rates up to 1,200 bits per second through a data subset installed by the international carrier in the customer's office. See Fig. 1. Associated with the data subset, RCA Communications, Inc. also provides an alternate-use switch for controlling a conventional teleprinter for use by the customer in coordinating the call by exchanging instructions over the teleprinter. Thus, the channel can alternately be used for data and teleprinter control by a single switch under the subscriber's control.

Since the service is an on-line transmission and reception facility with no storage of any kind between the two subscribers, the terminal data transmission equipment at both ends of the channel must be compatible with respect to code, format, and speed.

SOME TECHNICAL DETAILS

Most data transmission equipment which may be purchased or leased in the United States senses data from punched cards, perforated tape or magnetic tape and transmits a high-speed serial DC bit stream from its terminals. While this DC bit stream can be exchanged directly between the terminal equipments within the same office, it is not suitable for transmission over long-haul cable or wireline circuits and so, must be converted to a different form of transmission. The data subset provided by the common carrier and connected to the transmission line is a modulator and demodulator, sometimes referred to as a *modem*, which performs the translation from a DC serial pulse train into another form which will pass through all of the various transmission systems used over long-haul circuits. This form of transmission is usually frequency-shift modulation or, in some cases, vestigial sideband transmission.

Frequency shift modulation utilizes two frequencies, each of which represents the binary *1* or *0* of the DC bit stream. As the data signal from the subscriber's transmission equipment changes its level from + to *0* or + to −, the frequency transmitted by the data subset alternates accordingly conveying this information. Since the two frequencies produced by the data subset are sine wave in nature (that is, following smooth sine curves), they can readily pass through the many kinds of carrier systems, coaxial cables, microwave, and other transmission facilities utilized throughout the international voice channel network. In the subscriber's office, at the receiving point, a similar data subset converts the two received tones back into DC pulses to operate the companion data reception equipment producing an exact duplicate of the original punched card, paper tape, or magnetic tape for immediate use by other data processing equipment.

CHANNEL CO-ORDINATION AND ERROR PROTECTION

The teleprinter provided in the subscriber's office can be used for exchanging operational instructions between the subscribers, to request such things as a manual retransmission of certain portions of the data, to advise the distant end to commence transmission in the reverse direction, and to establish sched-

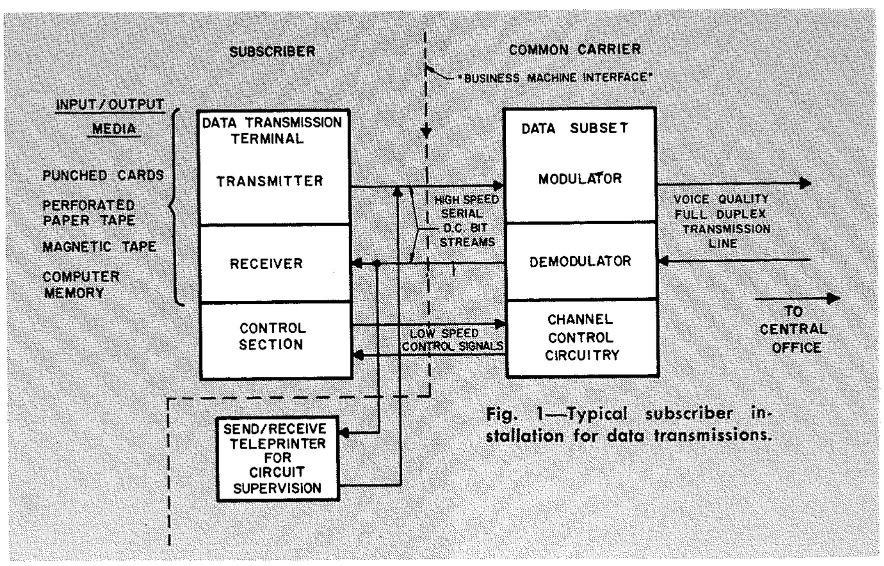

Fig. 1—Typical subscriber installation for data transmissions.

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ules for future Datatelex calls. The subscriber's data transmission equipment can take a wide variety of forms, the simplest of which is merely a high-speed perforated-tape reader and punch. If the budget permits, more sophisticated data transmission terminals can be acquired, many of which are capable of complete procedure programming to include fully automatic control of transmission and reception in both directions, with fully automatic error detection and correction features.

The most common form of error detection and correction utilizes the block-coding technique. In this form of terminal equipment, a large number of data characters are grouped into a fixed-length block, encoded with block or matrix parity and transmitted with conventional start-of-block and end-of-block signals much the same as those used in magnetic tape operation. Group or block parity systems add one or more characters at the end of the group of information characters to verify the odd or even total of the pulses in each code position. Thus, if a summation of all of the first elements of all characters in the block totals to an odd number, the first element of the added parity character would be a binary *1*. If the odd-even count at the receiver does not agree with the parity character, an error is presumed and a request for repetition is transmitted back to the original transmitter. Such simple coding schemes will only detect the odd number of errors which occur—that is, one, three, five, seven, etc. errors. For extremely high reliability, additional protection against error can be obtained by adding matrix parity characters at the end of the block. These characters are derived by arranging the information characters within the block into a mathematical pattern which interleaves the code elements in a manner which covers most, if not all, possible error combinations.

When an error is detected, the *proceed-to-transmit* signal in the reverse direction is withheld by the terminal receiving the error, calling for a retransmission of the preceding block. Since the error rate over long-haul data transmission channels may vary from point to point depending on the particular facilities in use, the overall performance of the channel can be controlled by varying the block lengths to optimum size. The proper adjustment of block length for a particular transmission medium will provide the maximum rate of information transfer and the lowest undetected error rate.

THE FUTURE OF INTERNATIONAL DATATELEX

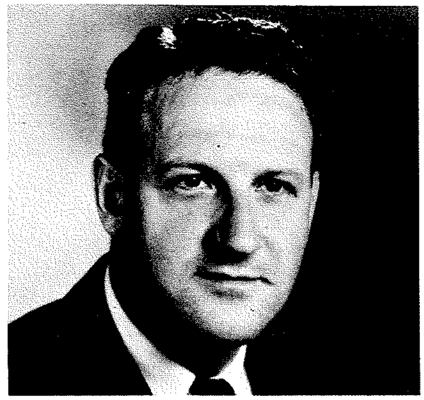
With suitable buffering equipment, present commercial computers could talk directly to each other via this service without the necessity of going through a punched card, paper tape or magnetic tape medium; however, in this event, the interface equipment between the computer and the data subset would have to be programmed to perform all of the two-way control functions and error detection and correction facilities provided by the usual data transmission equipment.

While data is exchanged within the United States over voice grade channels, the cumulative distortion of the channel from end to end, when extended to overseas points, would require, in most cases, regeneration at the international gateway to a near-perfect signal prior to retransmission to the overseas points.

Due to the wide variety of codes, formats, and transmission speeds now used for data transmission, an off-line equivalent of Datatelex service may be required to facilitate interconnection of two subscribers with different terminal equipment. In this type of service, the subscriber would place his Datatelex call to the international gateway of RCA Communications, Inc. where his entire transmission would be recorded for retransmission in a new code, speed, or format to match the terminal equipment of the called subscriber. This type of service would permit exchange of data between subscribers with different terminal equipment and in accordance with schedules suitable to the variation in office hours throughout the world's time zones.

Over the past few years, the demand for data transmission service in the United States has been growing consistent with the increased use of computers to control and co-ordinate widely-dispersed corporate operations. With this view in mind, the provision of long-haul international data transmission service to any point in the world must be considered, bearing in mind that only a limited number of countries can be directly reached by a high-quality transoceanic cable. To reach the many countries which cannot be reached by modern coaxial cables, we must consider improving long-haul, high-frequency radio transmission facilities for providing extremely reliable data transmission circuits with acceptable error rates. This, too, is in the planning stage with many of the major problems already resolved.

Satellite transmission systems, which are also in the commercial planning stages, will offer large bundles of high-quality voice channels for carrying the large volumes of international data exchange.



ROY K. ANDRES received the BSEE from New York University and attended MIT for graduate studies in switching and computer theory. Mr. Andres joined the Engineering Department of RCA Communications in 1946 where he participated in the conversion of international radio-telegraph circuits from Morse operation to the 5-unit printing telegraph torn-tape system. Since 1946, he has engaged in development of 5-unit telegraph switching systems, multiplex systems, automatic switching systems for microwave links, and data transmission systems; he holds patents in these and other fields. Presently, Mr. Andres is responsible for Automation and terminal Systems Engineering. In 1964, he will complete all operational aspects of the new Electronic Telegraph System using high-speed, stored program, digital computers. Final automation of the worldwide Telex network will also be completed permitting direct keyboard-to-keyboard conversation. Mr. Andres is a member of the IEEE and the professional-technical groups on Circuit Theory, Communications Systems, Electronic Computers, and Medical Electronics.

Fig. 2—RCA *Datatelex* used at Socony Mobil for overseas transmission; input data such as magnetic tape, paper tape, and punched-card forms can be sent by *Datatelex*.

GENERATION OF OPTICAL HARMONICS

The generation of optical harmonics was first reported[1] in an experiment in which coherent radiation from a ruby laser was brought to a focus in a quartz crystal. The interaction of the wave and the crystal converted red radiation (6,943 angstroms) into ultraviolet (3,472 angstroms). Subsequently, a number of investigators reported harmonic generation in a variety of materials, with radiation from both ruby lasers and neodymium lasers (10,600 angstroms). For research, harmonic generation provides a means of determining the properties of certain crystalline materials by direct interaction between matter and the intense electric and magnetic fields available from laser sources of electromagnetic radiation. For hardware applications, harmonic generation can produce high-power coherent radiation at frequencies heretofore unavailable for the new class of coherent optical instruments and systems—e.g., rangefinders, tracking equipment, communications systems, underwater illumination. Furthermore, this phenomena is probably a precursor to the discovery of other interactions with matter which will lead to components that can perform basic functional operations similar to those of conventional electronics. It would be highly desirable, for example, to perform multiplication, amplification, frequency conversion, coincidence effects, and a host of other unit functions which are necessary to implement complex systems at optical frequencies. Harmonic generation gives new impetus to the search for new techniques to accomplish these basic functions.

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IN the exposition which follows it is the intention of the author to acquaint the reader in some detail with certain aspects of harmonic generation but to make no attempt to present a comprehensive dissertation. The limited theoretical discussion which serves only to set forth the most salient features of the type of harmonic generation under consideration here is followed by a brief discussion of the results of current experimental work conducted at ASD Burlington under contract to the Bureau of Ships, U.S. Navy (Contract No. NObsr 87569).

Final manuscript received February 24, 1964

THEORETICAL DISCUSSION

The simplified and schematic representation of the theory of optical harmonic generation given in this section is essentially that developed by P. A. Franken.[2]

The electric polarization P of a dielectric material is:

$$P = XE(1 + a_1E + a_2E + \cdots) \quad (1)$$

Where: E is the applied electric field, X is the normal polarizability constant and a_1, a_2, . . . are constants which depend principally on the crystal electric fields. It is because of the smallness of these latter constants and the lack of intense coherent electromagnetic radiation that until recently, all but the first term in Eq. 1 were neglected for practical purposes. With the advent of lasers it became possible to generate intense coherent electromagnetic radiation which is of sufficient magnitude to result in appreciable contributions from the terms beyond the first. The second term is discussed in the following paragraphs, since it accounts for the production of the second harmonic. This is implied by noting that the periodic contribution to the polarization due to this term is dependent on cos $2\omega t$, where ω is the fundamental frequency. That is, if the optical electric field is $E = E_o \sin \omega t$, then:

$$P = Xa_1E_o^2 \sin^2 \omega t \quad (2)$$
$$= Xa_1 \frac{E_o^2}{2}(1 - \cos 2\omega t)$$

Where: E_o is the amplitude.

It should be noted at this time that there is a symmetry restriction implied by Eq. 1 which must be satisfied if the even harmonics are to be produced in significant quantities. For isotropic materials or crystals with a center of inversion symmetry, the polarization P must exhibit a reversal in sign when the electric field E is reversed. This requirement can only be met if the even order terms in Eq. 1 vanish. Another way to state this restriction is that a power expansion about zero of the polarization function

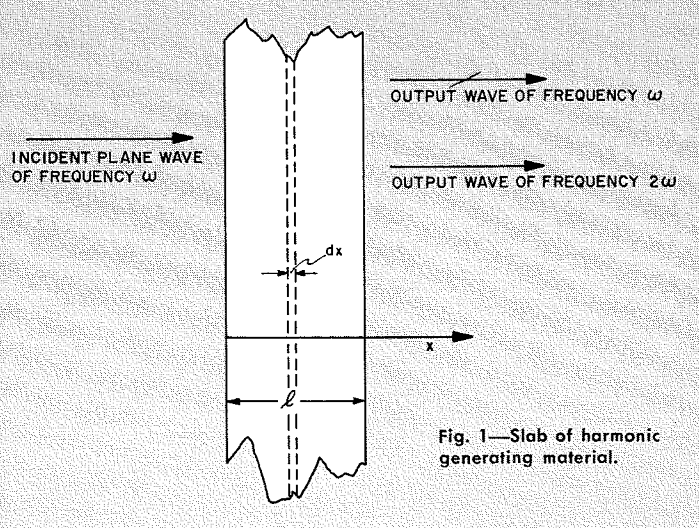

Fig. 1—Slab of harmonic generating material.

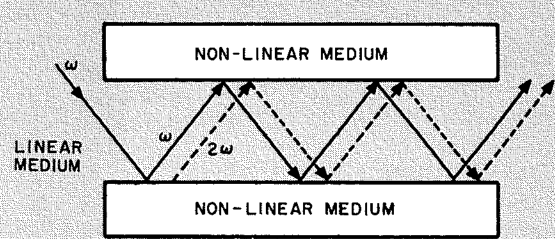

Fig. 2—Harmonic generation by multiple total internal reflections.

which is symmetrical about the origin cannot contain even order terms. Thus, in general, it is necessary to have asymmetries in the material to be used in the production of the second harmonic. This can be achieved by utilizing crystals such as potassium dihydrogen phosphate (KDP) and quartz, which are asymmetrical, or by applying a DC electric field to a crystal such as calcite which has a center of inversion symmetry. The externally applied DC field shifts the operating point on the P vs. E curve from zero to another point about which there is an effective asymmetry.

Consider now a plane wave of frequency ω incident upon an infinite plane slab of crystalline material and of thickness l, as shown in Fig. 1. Consider further that the material transmits 100% of both the fundamental and second harmonic wave. The electric field in the crystal at the fundamental frequency is $E_o \sin(k_1x - \omega t)$, and the amplitude of the polarization $P^{2\omega}$ at frequency 2ω can be expressed as:

$$P^{2\omega} \alpha \sin(2k_1x - 2\omega t) \qquad (3)$$

Where: k_1 is the wave vector for the fundamental. The second harmonic electric field $dE^{2\omega}$ at the output face of the slab due to the harmonic polarization of an element dx in the slab is:

$$dE^{2\omega} \alpha\, dx \sin\left[2k_1x - 2\omega(t - t')\right] \qquad (4)$$

Where: t' is the time it takes the harmonic radiation to propagate through the crystal; t' is specified by:

$$t' = \frac{l - x}{v^{2\omega}} = (l - x)\left(\frac{k_2}{2\omega}\right)$$

Where: $v^{2\omega} = 2\omega/k_2$ is the phase velocity of the second-harmonic radiation. The

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total harmonic electric-field at the exit surface is:

$$\int_0^l dE^{2\omega} \alpha \left[\frac{1}{2k_1 - k_2} \sin \tfrac{1}{2}\, l(2k_1 - k_2)\right] \sin\left(lk_1 + \frac{lk_2}{2} - 2\omega t\right) \qquad (5)$$

And, intensity is:

$$I^{2\omega} \alpha \frac{\sin^2 \frac{1}{2}\, l(2k_1 - k_2)}{(2k_1 - k_2)^2} \qquad (6)$$

Since k_1 and k_2 are equal to $\omega\, n_1/c$ and $2\omega\, n_2/c$, respectively, where n_1 and n_2 are the indexes of refraction for the fundamental and the second harmonic and c is the velocity of light, the intensity can be expressed as:

$$I^{2\omega} \alpha \frac{\sin^2\left[\frac{l\omega}{c}(n_1 - n_2)\right]}{\left|\frac{2\omega}{c}\right|^2 (n_1 - n_2)^2} \qquad (7)$$

In general, $I^{2\omega}$ is a periodic function of l and it is a maximum when:

$$\frac{l\omega}{c}(n_1 - n_2) = \frac{\pi}{2}(2N - 1) \qquad (8)$$

Where: N is an integer. Solving for l:

$$l = \frac{\lambda}{4(n_1 - n_2)}(2N - 1) \qquad (9)$$

If n_1 can be made equal to n_2, it is seen from Eq. 7 that:

$$I^{2\omega} \alpha \tfrac{1}{2} l^2 \qquad (10)$$

i.e., the intensity at the exit face of the dielectric, is directly proportional to the square of the thickness of the slab.

It is possible in certain crystals which are birefringent to obtain $n_1 = n_2$, and it is this approach which has been extremely successful in the production of second harmonic radiation and the one which will be discussed in greater detail below. There are, however, several other techniques which have been proposed and two of these will be described first.

One method[2] is to use a stack of separate plates such that each plate has an

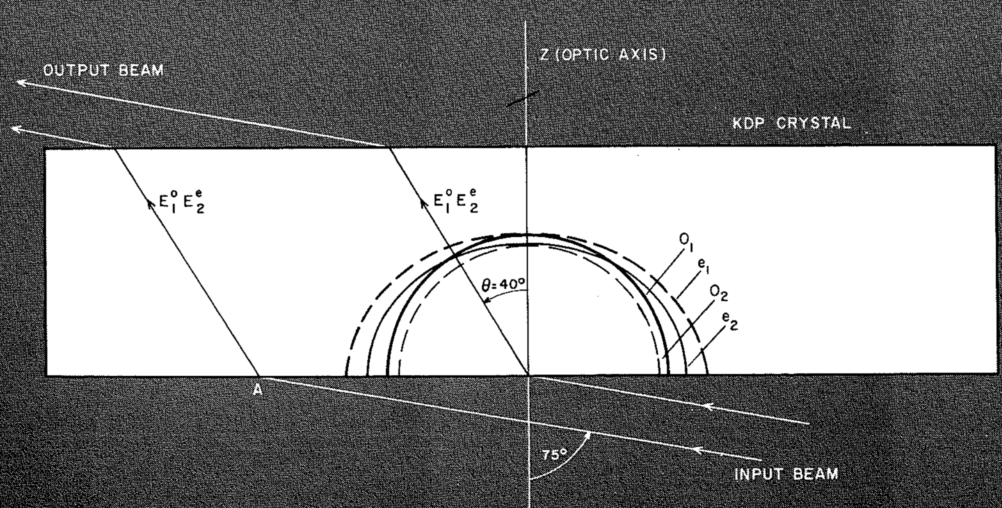


Fig. 3—Index matching geometry.

optical thickness which is an odd integral multiple of the wavelength and each alternate crystal in the stack has an orientation of its crystallographic axes which results in a reversal of the second harmonic polarization. In this manner, the output intensity should increase as the square of the number of plates in the stack. A drawback to this technique is that there are reflections at the interfaces which cause increasingly greater losses as the number of plates is increased. On the other hand, the overall gains to be expected should be greater than these losses.

Another interesting technique for the production of optical harmonics is based on the reflection of coherent light from dielectric interfaces. A method suggested by Bloembergen and Pershan[3] is depicted in Fig. 2. A fundamental wave travels in a dense linear fluid medium between two nonlinear walls at an angle with the interfaces such that repeated total internal reflections take place. The distance between the plates and the dispersion in the linear medium can be chosen so that on each reflection second harmonic radiation is generated with the correct phase to increase the harmonic intensity.

INDEX MATCHING

The previous section indicated the amount of second harmonic at the exit face of the crystal is an oscillating function of the crystal thickness dimension. It was further shown that if the refractive index for the fundamental and second harmonic waves n_1 and n_2, respectively, are equal the amount of second harmonic radiation at the exit surface of the crystal increases as the square of crystal thickness. A method for achieving this condition was reported by Giordmaine[4] and Maker et al.[5] Their method is based on the fact that in some anisotropic crystals the birefrigence is such that the wave surface for an ordinary wave at the fundamental frequency intersects the wave surface for an extraordinary wave at the second harmonic frequency. Along a direction defined by the origin of the wave surfaces and this line of intersection the index for the fundamental and second harmonic waves is equal to each other. For a uniaxial negative crystal such as KDP this direction is about 40° with respect to the optic axis for fundamental radiation with a wavelength of 1.06 microns (neodymium-glass laser output wavelength).

Fig. 3 shows a wave surface diagram for KDP and the geometry of the input and output beams in some of the experiments described in the next section. The incident parallel 1.06-micron beam makes an angle of 75° with the optic axis which is normal to the incident face of the crystal. Since the refractive index of KDP for 1.06-micron radiation, as determined by Miller and Savage[6] is 1.495, the angle of refraction is about 40°. At this angle, the refracted beam is directed through the intersection of the ordinary wave surface for the fundamental and the extraordinary wave surface for the second harmonic.

EXPERIMENTAL RESULTS

An experimental program is in progress to determine the most efficient methods of harmonic generation and to study the conversion characteristics of various crystalline materials. A Q-switched neodymium-glass laser has been used to generate intense pulses of short duration and various modes of passing the radiation through the crystalline material have been investigated. A typical experimental arrangement is depicted in Fig. 4. The results obtained so far are incomplete but a number of gross effects have been observed. Utilizing KDP as the nonlinear medium, an increase in conversion efficiency has been observed with both an increase of the fundamental input power and an increase in length of material traversed. The exact character of the relationships has not been determined but conversion efficiencies from 10^{-6} to 10^{-1} have been observed under a variety of conditions. The maximum achieved to date (10%) was accomplished in a 1-inch KDP crystal with a collimated input fundamental beam of 2 Mw. The cross-sectional area of the beam is 0.31 cm^2 which implies an intensity of 6.4 Mw/cm^2 for a uniform beam. The KDP crystal was cut with its input and output face at 40° to the optic axis so that the index matching condition was satisfied with the input beam at normal incidence.

Since conversion efficiency increases as a function of the input intensity it seems reasonable to expect additional enhancement by the use of beam concen-

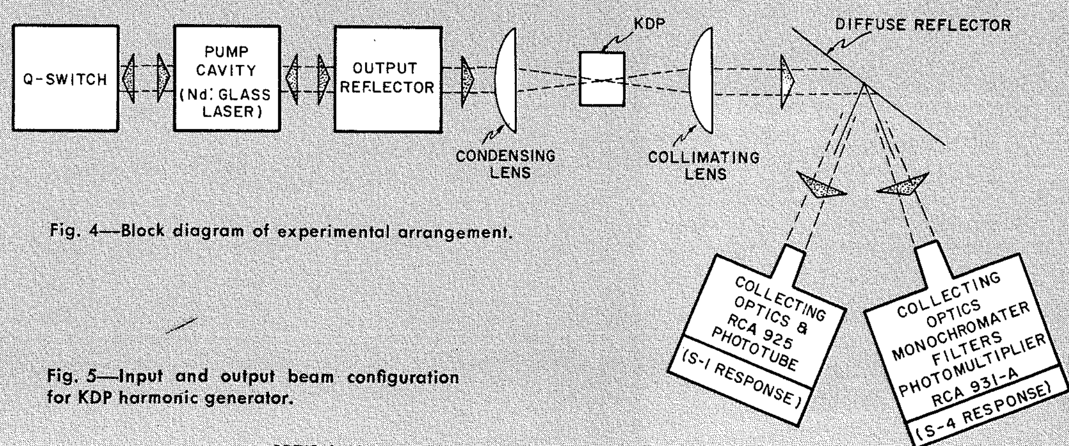
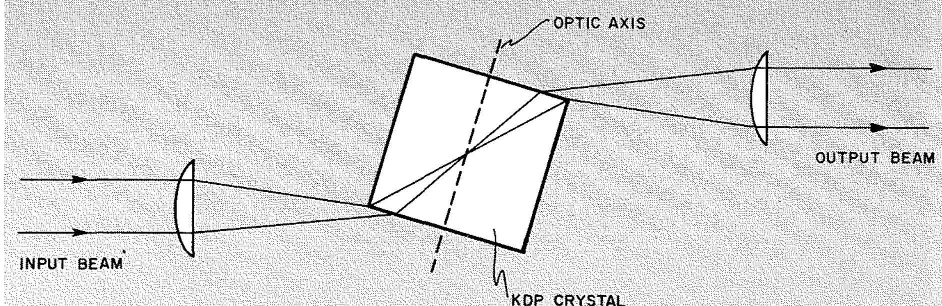


Fig. 4—Block diagram of experimental arrangement.

Fig. 5—Input and output beam configuration for KDP harmonic generator.



trating optics such as a simple telescope made of simple lenses or by the use of simple focusing with subsequent recollimation as depicted in Fig. 5. The use of a telescope is in principle the better technique but in practice has a practical disadvantage. For weak sources, a long-focal-length lens will be required to achieve the amount of concentration desirable, since this concentration is proportional to the square of the ratio of focal lengths of the two lenses (objective and ocular). With the latter technique, it is possible to concentrate strongly in the focal regions with simple lenses of short focal length. The chief disadvantage of this method, however, is that one does not have a collimated beam propagating through the crystal and only a fraction of all the rays travel in a direction which satisfies the index matching condition. Both methods have been used but significant quantitative results for comparison purposes have not been obtained to date. Another problem which is encountered in experiments of this kind is the destruction of the nonlinear material by the intense fundamental radiation. This limitation has been examined for KDP by the following method. The output of the laser is brought to a focus by a plano-convex lens with a focal length of 6 inches. The KDP crystal is then placed close to the output side of the lens and successively moved nearer to the focal plane until the crystal just begins to become damaged. For KDP the intensity at the "threshold for damage" is about 80 Mw/cm^2. The nature of the damage has not yet been completely determined, but it appears as a series of small bubbles in line as a permanent track marking the passage of the beam through the crystal.

The output waveform of the second harmonic radiation produced by fundamental radiation from a Q-switched neodymium-glass laser is similar to the waveform of the fundamental pulse. A typical 200-kw second-harmonic (5,300 angstroms) pulse with a width of about 30 nsec is shown in Fig. 6.

The spectral nature of this second harmonic radiation is characterized by 80 equally spaced modes which may be due to some interferometric component in the optical system of the fundamental source or to the harmonic generation components. The overall width of the green radiation is about 24 angstroms and mode spacing is about 0.3 angstroms. Several modes are shown on an expanded scale in Fig. 7.

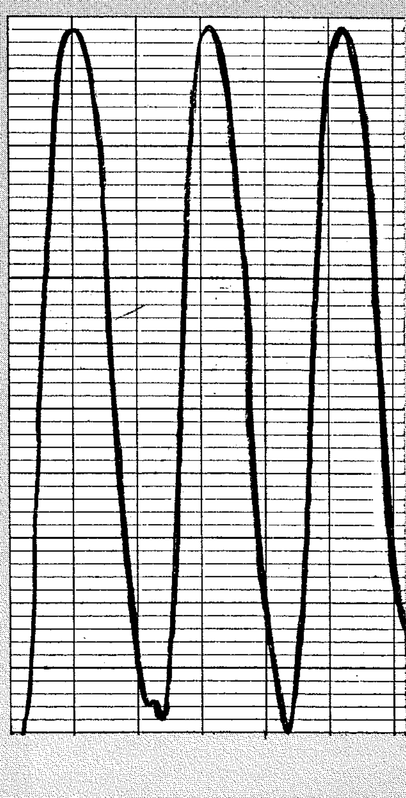


Fig. 7—Spectral modes of the second harmonic (5,300 angstroms). Two horizontal divisions = 0.304 angstrom.

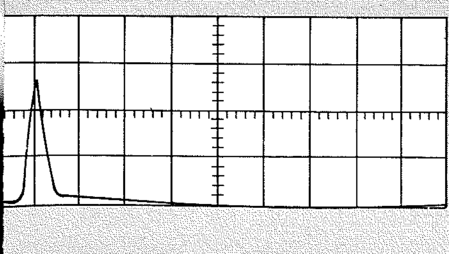


Fig. 6—Temporal waveform of 200-kw coherent green second harmonic radiation (5,300 angstroms) pulse produced by a neodymium-glass laser and KDP crystal. (Abscissa 10 nsec per smallest division.)

CONCLUSIONS

Techniques for the production of second harmonic radiation have been developed sufficiently to demonstrate the utility of this approach for frequency translation of high power coherent sources important in applications such as rangefinders, active tracking systems, and communications. As an example of its special utility in a particular application, a completely self-contained submersible transmitter utilizing second harmonic radiation (5,300 angstroms) with a Q-switched neodymium-glass laser for the fundamental radiation (10,600 angstroms) has been constructed and tested under water at the David Taylor Model Test Basin in Washington, D.C. There is a particular advantage in this case due to the fact that transmission in sea water is maximal for green radiation.

It is apparent that additional developments will result in further improvements in conversion efficiency for high power sources, and that techniques will be found to improve the conversion efficiencies for low power sources also. Perhaps an even more important consequence of this phenomenon is the new impetus it has given to research and development in the potentially important technology of interactions between coherent optical radiation and matter.

ACKNOWLEDGEMENTS

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GALLIUM ARSENIDE P-N JUNCTION INFRARED ENERGY SOURCES

The high-efficiency radiation attributed to the radiative recombination of hole-electron pairs in forward-biased gallium-arsenide p-n junctions has opened a new era in the semiconductor industry. The radiation is incoherent at low current densities and becomes coherent at high current densities.[1,2] Only the incoherent mode of operation will be considered here. The phenomenon which produces incoherent radiation has been employed in the past to study band structure and crystalline quality.[3] Other applications of this radiation are only recent innovations; however, they have already proved to be of vast importance and have significantly broadened the horizons for the applications engineer in communications, computers, control circuits, display equipments, and illumination. In this paper, the general characteristics of the radiation from gallium arsenide junctions are discussed.

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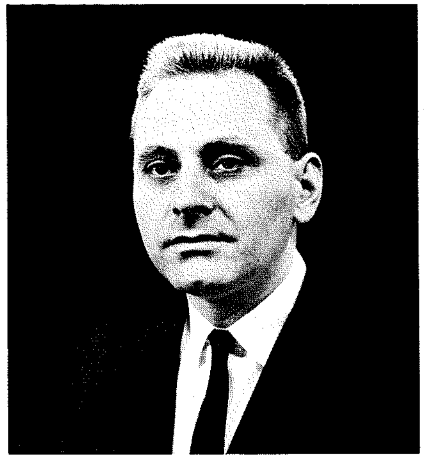
Electronic Components and Devices

Somerville, N. J.



MICHAEL F. LAMORTE received the BS from Virginia Polytechnic Institute in 1950 and the MEE from the Polytechnic Institute of Brooklyn in 1951. He held a Teaching Fellowship in 1950-51 and a Research Fellowship in 1951-52 at the latter institution. He was an Adjunct Professor in the E.E. Graduate School of University of Pittsburgh. From 1952 to 1955 he was at the Signal Corps Engineering Labs, Fort Monmouth, N. J., in study of fundamental properties of semiconductors. From 1955 to 1959 he was with the Westinghouse Electric Corp., investigating device theory and technology. Special contributions were made to high-power silicon devices, crystalline material and diffusion studies. In October 1959, he joined the RCA Semiconductor and materials Division at Somerville, N. J., where he has been a Project Leader in Advanced Development, responsible for R&D on varactor diodes and GaAs solar cells. Author of several papers, he is a member of the American Physical Society, the IEEE and IEEE-PTGED, Phi Kappa Phi, Tau Beta Pi, and Eta Kappa Nu.

Light is emitted in a forward-biased gallium-arsenide p-n junction when recombination of injected carriers occurs. This action is the result of space-charge recombination or of diffusion or tunneling mechanisms. Thus, electrical energy is converted to radiant energy. Although the device in which this effect is used is relatively new, a wealth of information exists for its reciprocal circuit element—the solar cell.

The reciprocal phenomenon occurs in solar cells when the junction is irradiated by radiant energy to which it is sensitive. The radiation generates hole-electron pairs which diffuse toward the junction and subsequently are separated by the junction built-in field; it is this separation of the carriers which results in the conversion of radiant energy to electrical energy. Thus, the conversion mechanisms in solar cells and in forward-biased gallium-arsenide p-n junctions are reciprocal.

Many of the problems confronted in the fabrication and design of these reciprocal circuit elements are common to both devices. In one case, it is necessary for the radiation incident on the surface to be absorbed in the junction region; in the other, it is necessary for the radiation generated in the junction region to escape the semiconductor. The passage of light in both directions is aided by optical coatings. Series resistance in both cases results in power loss. In the solar cell, power is dissipated in this resistance which otherwise would be delivered to the load. Therefore, solar-cell conversion efficiency is reduced. For the light source, the series resistance results in a power loss and, in turn, causes heating of the junction. Both effects reduce the power efficiency of the incoherent radiation.

The efficiency of energy conversion in both solar cells and light sources is affected by the lifetime of hole-electron pairs; long lifetime is required in both devices. In solar cells, longer lifetime allows a larger fraction of the minority carriers to diffuse to the junction. In light sources, the lifetime of the hole-electron pairs should approach its limiting value —the radiative recombination value. At this limiting value, all minority-carrier recombination occurs between the conduction and valence band edges or between levels close to these band edges. This behavior is precisely what is desired.

Data on conversion efficiency are presented below in terms of power density in units of watts per square centimeter of active area of the junction. This power density is that actually measured by a calibrated detector. The efficiency is determined on the basis of the actual power emanating from the diode; the value obtained in this way is referred to as the external efficiency. Because all the radiant energy does not leave the device, corrections can be made for the reflectance at the semiconductor-to-air interface, for the total reflection which results for incident angles greater than the critical angle, and for the isotropic radiation which is assumed in the recombination process in the junction region. The efficiency thus calculated, the internal efficiency, is higher than the external efficiency. These corrections are not applied in the data presented, and the efficiency discussed is the external efficiency.

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CHARACTERISTICS OF INCOHERENT RADIATION

The radiation may exit from either the p- or n-type surface of the gallium-arsenide junction and, for special geometries, from the edge of a pellet where the p-n junction terminates. The spectra from various regions may be different because of the change in the absorption characteristic. These differences will not be discussed further.

Effect of Temperature on the Radiation

The effect of temperature variations on the incoherent radiation is shown by Figs. 1 and 2. Fig. 1 shows the radiation spectra for the same current at two temperatures, while Fig. 2 shows that the peak radiation intensity is confined to a line (referred to as the band-gap line) whose energy is very nearly equal to that of the band gap. If unwanted impurities are present or if the crystalline quality is poor, other radiation lines may appear which exhibit energy levels significantly less than the band-gap energy. These additional lines are caused by other recombination processes which compete with those that produce the band-gap line. This competition causes the band-gap radiation line to become less intense, and the efficiency for this radiation line is reduced. However, not all competing recombination processes are radiative. When other processes occur, the band-gap radiation line may be the only one in the spectrum, but it will still exhibit a lower efficiency. When all recombination is confined to that which produces the band-gap line, the lifetime of minority carriers is the limiting value, the radiative lifetime; this lifetime is lower than the lifetime value for the competing processes.

In Fig. 1, the radiation intensity for the same current is shown to be considerably higher at lower temperatures. This condition may be attributed to two possible phenomena: 1) At lower temperatures, the number and the magnitude of the competing processes are reduced; as a result, the efficiency of the band-gap line is increased. 2) As the temperature is decreased, less absorption of the band-gap line occurs during its traverse to the exit surface. There is evidence to believe that the latter factor may be the dominant one.

The inverse relationship between the peak energy value of the band-gap line and temperature is attributed to the fact that the band gap of a semiconductor has a negative temperature coefficient. The energy levels in the band gap also shift with the band gap. However, as shown in Fig. 2, the band-gap temperature coefficient is -4.9×10^{-4} ev/°K, while that for the radiation shifts is -4.85×10^{-4} ev/°K. Thus, at higher temperatures the radiation is subjected to greater absorption because the radiation is closer to the band edge, where the absorption is strong.

Influence of Current on the Radiation

The spectrum is influenced by the junction current. This influence is shown in Fig. 3, which shows spectra for three values of current. For the range of values considered, the radiation intensity becomes higher as the current is increased. The line width and the wavelength, however, are not affected by the changes in the current. If a higher base-impurity concentration is used, a shift to a shorter wavelength with increasing current values may be observed. This shift in the wavelength has been attributed to a band-filling mechanism.[4]

The incoherent radiation is found to be linearly proportional to current. In one case, the current was increased up to 800 amp/cm^2 (somewhat below the laser threshold) at a temperature of 77°K, and the radiation varied linearly with current over several orders of magnitude. This characteristic makes p-n junction radiation particularly attractive for communication applications.

In Figs. 4 and 5, the total radiation exiting the diode is shown to be a linear function of the current over a wide range of values at a temperature of 77°K. This radiation is integrated over the spectrum as well as over space. The data in Fig. 4 were taken with the diode junction under pulsed conditions of 1-microsecond current pulses. This mode of operation was used to prevent excessive heating of the junction. For current densities greater than 180 amp/cm^2, the radiation was found to be linear up to 1,500 amp/cm^2, and it is probably linear to even higher current values. At 1,400 amp/cm^2, the output power density is greater than 50

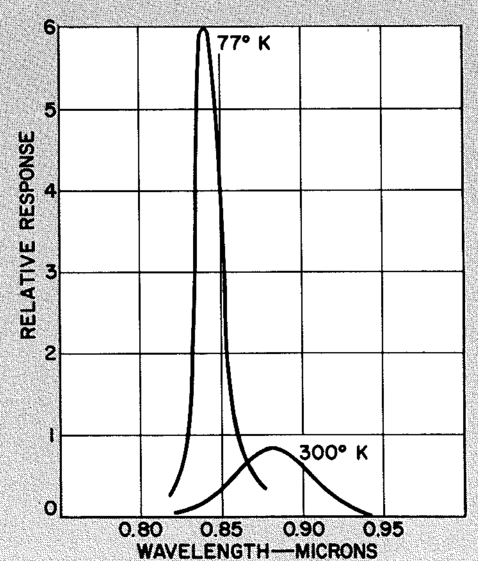

Fig. 1—Radiation spectra for a gallium arsenide infrared source at different temperatures.

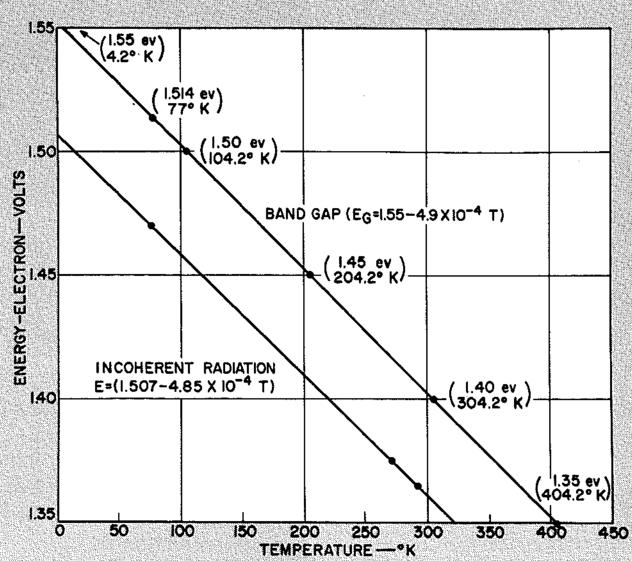

Fig. 2—Variations of the peak incoherent radiation and of the band-gap energy of a gallium arsenide diode as a function of the temperature of the band edge.

watt/cm^2 of the junction area. In this region, the output increases at a rate of 28 mw/amp.

The portion of the curve at low-current-density values is expanded employing a DC method. Fig. 5 shows that, in this region, the power varies linearly with current up to 10 amp/cm^2. For higher current values, the relationship tends to become nonlinear because of the junction temperature rise. Current values in excess of 18 amp/cm^2 result in excessive heating of the junction and a corresponding reduction in output power. Ultimately, the junction will be destroyed if the constant current is increased much beyond this value. Therefore, if linearity is to be maintained, the junction must not be heated. The maximum DC output power density for the gallium arsenide junction is 22.5 mw/cm^2 at 18 amp/cm^2, or a slope of 14 mw/amp. This value is half the slope obtained at the higher pulsed-current-density values. This difference is the result of changes in the radiation pattern and is not caused by any change in competing recombination processes. The broken portion of the line in Fig. 4 is inferred and does not represent measured values.

At a current density less than 18 amp/cm^2, the observed radiation pattern is very close to a Lambertian distribution. A typical example of the distribution is shown in Fig. 6. These data were taken on the same diode that was used to obtain the data shown in Figs. 4 and 5. The data in Fig. 6 were recorded under DC conditions. The solid angle at the half-power points is approximately 0.8π steradians. The radiation pattern for much higher pulsed current densities was also investigated for this diode and is shown in Fig. 7. At the higher current densities, the diode becomes more efficient because more light is emitted along the edges and contributes to the total light output. The data show that as the current density increases the pattern takes on a nearly isotropic shape. The pattern cannot become spherical because the mounting pedestal blocks the radiation path. The solid angle at the half-power points for the data in Fig. 7 at 800 amp/cm^2 is 1.6π steradians.

Fig. 8 shows the radiation pattern of a diode for which the emission from the edges is comparable to that from the p-type surface. For this condition, the radiation pattern is isotropic. This type of pattern usually occurs when the current density exceeds 10^3 amp/cm^2. The emission from the edge is shown to be greater than that from the p-type surface, which results from stimulated emission in the junction plane.

The power efficiency η is defined as:

$$\eta = \frac{1}{VI}\int_{\Delta\lambda} E_\lambda \, d\lambda \qquad (1)$$

Where: V is the applied voltage, I is the junction current, E_λ is the radiation in units of watts per micron, λ is the wavelength in microns, and $\Delta\lambda$ specifies the region over which the integral is taken. In a similar manner, the quantum efficiency Q may be determined as:

$$Q = \frac{qN}{I} \qquad (2)$$

Where: N is the number of photons emitted per second. The photon flux N may be written:

$$N = \frac{1}{\mathrm{h}\bar{\nu}}\int_{\Delta\lambda} E_\lambda \, d\lambda \qquad (3)$$

Where: h is Planck's constant and $\bar{\nu}$ is the average frequency of the line radiation. The quantum efficiency then becomes:

$$Q = \frac{1}{I\mathrm{h}\bar{\nu}/\mathrm{q}}\int_{\Delta\lambda} E_\lambda \, d\lambda \qquad (4)$$

The voltage V_o required to elevate electrons sufficiently to effect a recombination can be determined from:

$$V_o = \frac{\mathrm{h}\bar{\nu}}{q} \qquad (5)$$

If the series resistance of the diodes is negligible, then the applied voltage $V = V_o$. In that case, the power and the quantum-efficiency values are equal. However, if a dissipation loss is present, then $V > V_o$, and the power efficiency is less than the quantum efficiency, as is evident from a comparison of Eqs. 1 and 4. The internal quantum efficiency can approach 100%.

CHARACTERIZATION OF THE DEVICE

To characterize gallium arsenide junction devices fully, it is necessary to give a more complete description than is usually required for other types of optical devices. The parameters which are necessary for full characterization were indicated in the previous discussion. For example, the active area of the device should be given, as well as its shape, to determine the optical system required for use of the device. In some applications, the radiation pattern may suffice.

The value of constant current at which the radiation becomes nonlinear due to junction heating should be given, as well as the absolute maximum current allowed. This information should also be provided for pulse conditions, together with the pulse width and associated repetition rate.

The radiant power must be specified. Because this power may be expressed in a number of ways, the systems of units have, in some cases, led to confusion. (In this paper an attempt has been made to avoid this confusion by expressing power density in *watts per square centimeter*, or *milliwatts per square centimeter*, and energy in *electron volts*.) The radiant power can be conveniently specified in terms of the power density at the device surface or of that in space at a given distance from the surface. If the power density is specified at a distance away from the surface, watts per steradian is a suitable unit provided the radiation pattern is also given.

Another convenient parameter that helps to establish the character of gallium-arsenide devices is the change in radiant power with respect to junction current, dP/dI. The spectral-line width and wavelength of the device should also be given, especially if it is to be used with narrow-band optical filters.

At values of current density less than 100 amp/cm^2, the radiation is incoherent, unpolarized or only slightly polarized, and the radiation efficiency is less than 1.5% at 77°K for p-surface emission. The power efficiency will be less by an amount proportional to the diode series resistance. The radiation pattern is Lambertian. At 77°K, the width of the radiation line is 140 to 200 angstroms. New geometries have been invented to circumvent the limitation imposed by the critical angle.[5] This investigation has already resulted in output power and external efficiency many times greater than those reported in this paper.

At current values in excess of 100 amp/cm^2 radiation from the edges of the diode is also observed. Further increases in current cause the radiation pattern to approach more and more closely to an isotropic pattern that uniformly fills 2π steradians.

At still higher current densities, the laser threshold may be reached if the optical characteristics of the device are suitable. In general, some rather special device processing is required to reach this threshold.

CONCLUSIONS

Gallium arsenide infrared sources provide the engineer with a very versatile and useful new device. Because the radiation of the devices is linear, is directly modulated, and has a frequency response from DC to many hundreds of megacycles, many applications for them in communications, control circuits, and optical ranging suggest themselves immediately. Under pulsed conditions, output power of hundreds of watts can be produced. For pulsed conditions, 28 mw/amp has been observed at 77°K; for DC conditions, 14 mw/amp. The difference in these values is attributed to the current density employed.

In the future, higher power-density with higher efficiency is anticipated. Other semiconductors having different band-gap energy levels may be employed to fabricate diodes that emit in other portions of the spectrum.

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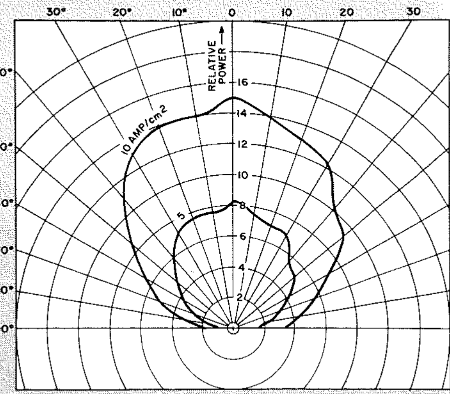
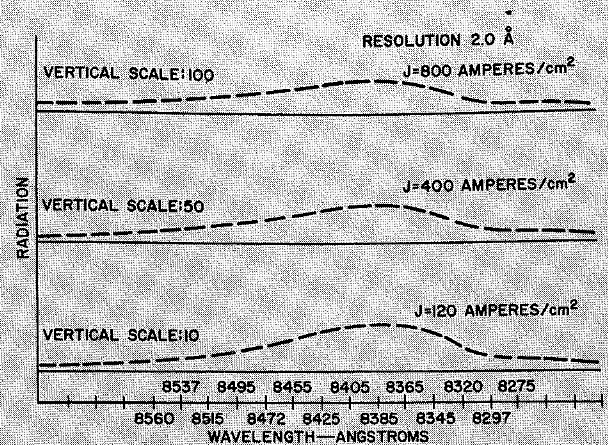


Fig. 6—Comparison of radiation patterns obtained at 77°K for different values of constant current.



3—Spectra of the pe surface of a gallium nide diode at different de current densities. a taken at 77°K with diode current provided 1-μsec pulses.)

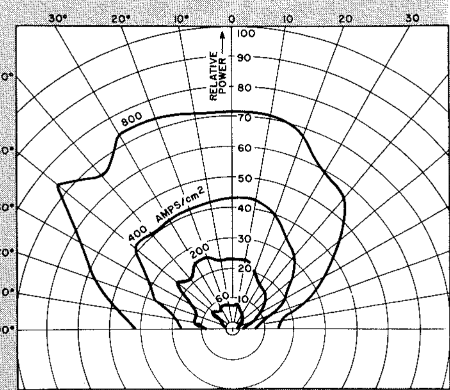
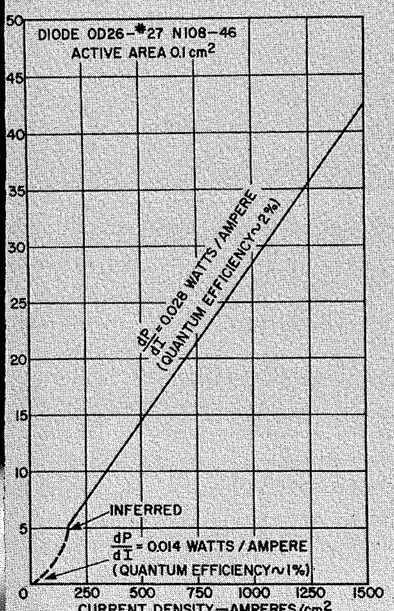


Fig. 7—Comparison of radiation patterns obtained at 77°K for different values of pulsed current (pulse width: 1 μsec; repetition rate: 30 pulses per second).



4—Peak radiation from a gallium nide diode as a function of the diode ent density with the diode current proed by 1-μsec pulses at a repetition rate 30 pulses per second.

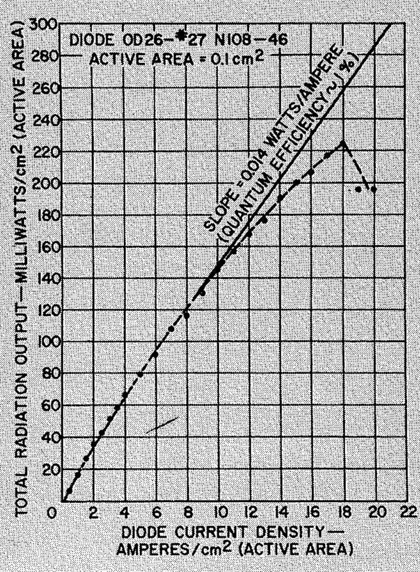


Fig. 5—Radiation from a gallium arsenide diode as a function of diode current at 77°K under DC conditions.

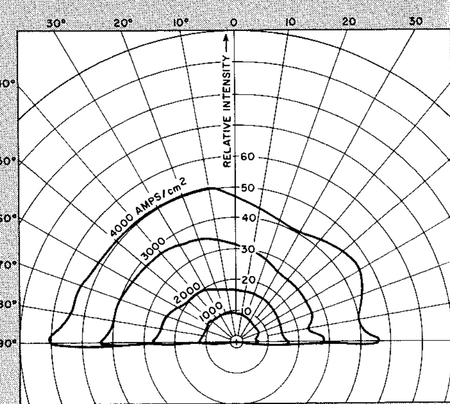


Fig. 8—Nearly isotropic radiation patterns obtained for different values of 1-μsec current pulses at a repetition rate of 30 pulses per second.

HF RECEIVER FIGURE-OF-MERIT MONITOR

Described is a project to determine the practicability of measuring the overall figure of merit of a shipboard receiving system in its operational environment, to develop methods and circuitry to achieve the desired goal, and to build a demonstration model. Experimental use of this general type of figure-of-merit system has shown it to be simple and effective. It permits convenient quantitative evaluation of receiver performance in its operating condition and will also detect degradation which can then be corrected before communication performance is impaired.

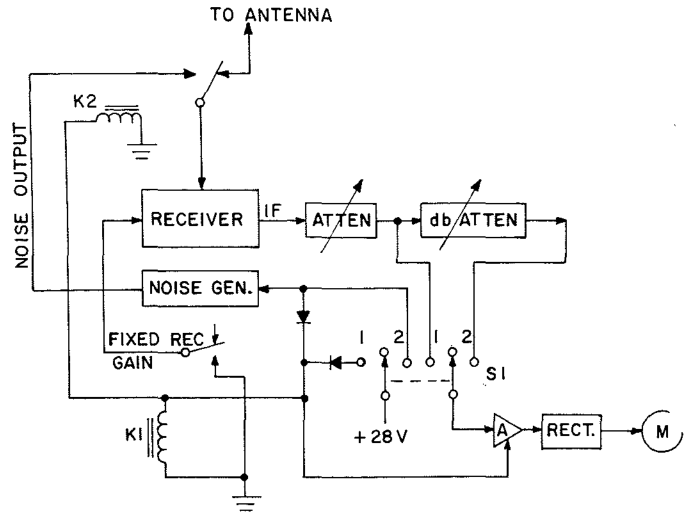


Fig. 1—Receiver figure of merit measuring circuit.

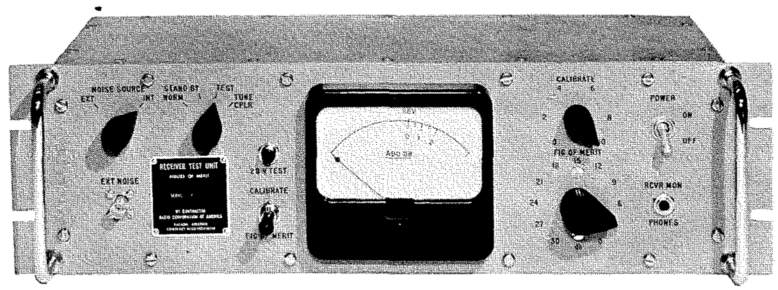


Fig. 2—Receiver test unit.

G. E. HANSELL and B. A. TREVOR
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In present shipboard and shore stations, there is normally no convenient method to determine receiver condition quantitatively unless gross degradation or complete failure occurs. Hence, a receiver may degrade below acceptable limits without being detected even with routine preventive maintenance. The proposed figure-of-merit system developed has the advantage that the receiver may be conveniently and accurately tested at any time at the operating frequency and at the operating IF bandwidth. It is known that a receiver may perform properly at some frequencies and bandwidths, but not at others.

A major objective in the figure-of-merit task is to develop the simplest measurement procedure to derive the most comprehensive information possible. The two most important receiver parameters for performance are sensitivity or noise factor, and gain. Therefore, a good measure of sensitivity or noise factor has been chosen as the basis of the figure of merit test. If a properly tuned and adjusted receiver passes this test, there is a high probability that it will give the desired communication performance.

Since sensitivity specifications for a particular receiver are different for various control settings, this type of measurement is not convenient for figure of merit tests. In addition, the signal generator must be set to an exact frequency and type of modulation. Generator setting can be avoided by using an impulse source having a flat line spectrum over the HF band. Meaningful results with this type of generator require knowing the receiver bandwidth. On the other hand, noise factor measurements made with a thermal noise generator are independent of receiver settings as long as the receiver input-output characteristic is linear. Hence, this type of measurement was chosen for the figure of merit test. The linearity requirement is best met by using the receiver IF output. Thus, settings of the audio limiter and overload of the AM diode are avoided.

FIGURE-OF-MERIT MEASURING CIRCUIT

Fig. 1 shows a figure-of-merit measuring circuit associated with a single receiver. This configuration uses a simple solid state noise generator previously described.[1] The noise generator should have a noise output which is flat over the entire tuning range of the receiver, usually from 2 to 32 Mc. The excess noise of the generator above the thermal level must be known. Then the figure of merit is definied to be *the increase in receiver noise output in db, when the noise generator is turned on.* (The relation between receiver noise factor and figure of merit is discussed later.)

The circuit of Fig. 1 provides a convenient means for measuring the figure of merit. Switch *S1* may be a key switch or toggle switch, preferably with a spring return to the center position. The input impedance of amplifier *A* must be high enough to bridge either attenuator without introducing appreciable error. Relay *K1* is shown with one contact to put the receiver on fixed gain. However, most HF receivers will require at least two leads and some will require three for this purpose. Relay *K1* can have the number of contacts required for any particular receiver.

The measuring procedure is quite simple. With switch *S1* in position *1*, the receiver is on fixed gain, the noise generator (turned off) is connected to the receiver antenna input, and the solid state amplifier is turned on. Under these conditions, the left-hand attenuator is adjusted to give a fixed reading on the meter *M*. Switch *S1* is then held in position *2*, which turns on the noise generator. The db attenuator (on the right)

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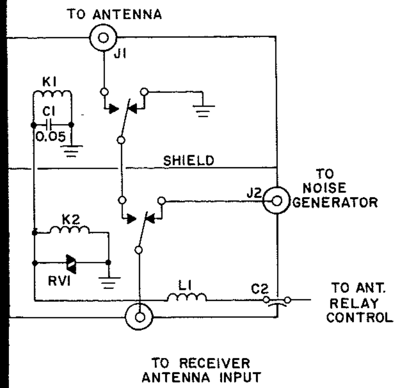


Fig. 3—Antenna switch unit.

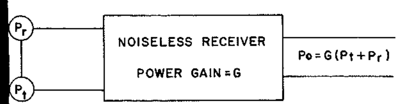
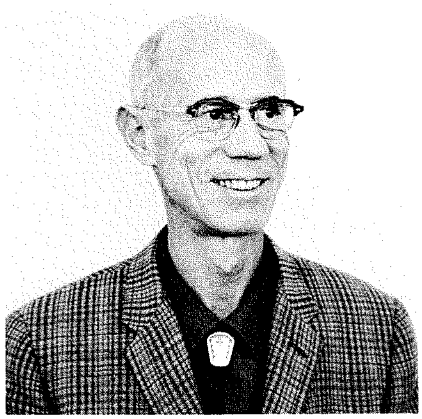


Fig. 4—Equivalent circuit of noiseless receiver.



BERTRAM A. TREVOR earned his BSEE in 1928 from Cornell University. He received the IRE Fellow Award in 1953 for contributions in the field of pulse multiplex communication systems and long range receiving equipment. Mr. Trevor joined RCA in 1928 where he was engaged in research, design, and advanced development in the fields of HF, UHF, and microwave receivers, telegraph and printer terminal equipment, single sideband equipment, diversity reception methods, propagation, antennas, transmission lines, and measuring equipment. In 1958 he transferred to the Tucson Systems Laboratory, where he has worked on communications Systems studies for the Army, Navy, Air Force, and the Marine Corps. He is presently Project Coordinator for a U. S. Navy Electronics Laboratory contract. Mr. Trevor is a member of the IEEE Professional Group on Communications Systems and Sigma XI. He has had 48 patents issued and has written numerous papers.

G. E. HANSELL received his BSEE degree from Purdue University in 1931. He has had over 32 years of design and development experience with RCA in the field of receivers including associated single sideband, frequency shift teletype and diversity equipments. He participated in the development of Minuteman cable communication equipment, and recently a U. S. Navy Electronic Laboratory contract concerning HF receiver figure of Merit Systems. Mr. Hansell is author of two and co-author of two technical papers and holds 6 patents. He is Senior Member of IEEE.

is adjusted to give the same meter reading. The figure of merit is then read directly from the db attenuator. This measurement takes only a few seconds to perform, and it should be noted that it may be made at *any* frequency and is *independent* of IF bandwidth setting.

It is very important that the antenna relay *K2* of Fig. 1 have low crosstalk to prevent atmospheric noise or signals on the antenna from reaching the receiver during a figure-of-merit test. The dual antenna switch unit shown in Fig. 3 provides more than 160-db isolation at 2 Mc and more than 110-db isolation at 32 Mc. It is of course necessary to provide adequate shielding and cabling to maintain good isolation.

Fig. 2 is a photograph of a receiver test unit, which was built for the Naval Electronics Laboratory, to be used as demonstration equipment. This is somewhat more complicated than that in Fig. 1. The R-390A receiver may be used without modification, but other types of HF receivers may require some modification to provide the IF output and necessary leads to disable the automatic gain control.

RELATION BETWEEN FIGURE OF MERIT AND NOISE FACTOR

The equivalent circuit of the receiver is shown in Fig. 4, where P_t is the available noise power per cycle of bandwidth from the generator source resistance R and is equal to KT, and P_r is all the receiver noise power per cycle of bandwidth referred to the receiver input.

The receiver noise factor power ratio is defined to be:

$$F = \frac{G(P_t + P_r)}{GP_t} \qquad (1)$$

Solving for P_r:

$$P_r = P_t\ (F-1) \qquad (2)$$

If we let N_g = the fixed excess power ratio of the generator source when the generator is on, then the ratio M of the receiver output with the generator *on* to the generator *off* is:

$$M = \frac{G(N_gP_t + P_r)}{G(P_t + P_r)} = \frac{N_gP_t + P_r}{P_t + P_r}$$

Substituting for P_r from Eq. 2:

$$M = \frac{N_g + F-1}{F}$$

Or,

$$F = \frac{N_g - 1}{M-1} \qquad (3)$$

where all terms are power ratios.

If N_g and M are known in db, they must be converted to power ratios to find F from Eq. 3. If both (N_g)db and (M)db are greater than 10 db, then:

$$(F)\,\text{db} \approx (N_g)\,\text{db} - (M)\,\text{db} \qquad (4)$$

For example, if (N_g)db = 20 db and (M)db = 10 db, Eq. 4 gives (F)db = 10 db, whereas Eq. 3 gives F = 11 or 10.4 db. The error in Eq. 4 becomes less the greater the value of M.

CONCLUSION

Experimental use of this general type of figure-of-merit system has shown it to be simple and effective. It permits convenient quantitative evaluation of receiver performance in its operating condition and will also detect degradation which can then be corrected before communication performance is impaired.

ACKNOWLEDGEMENT

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Fig. 1—RCA N-2 Font

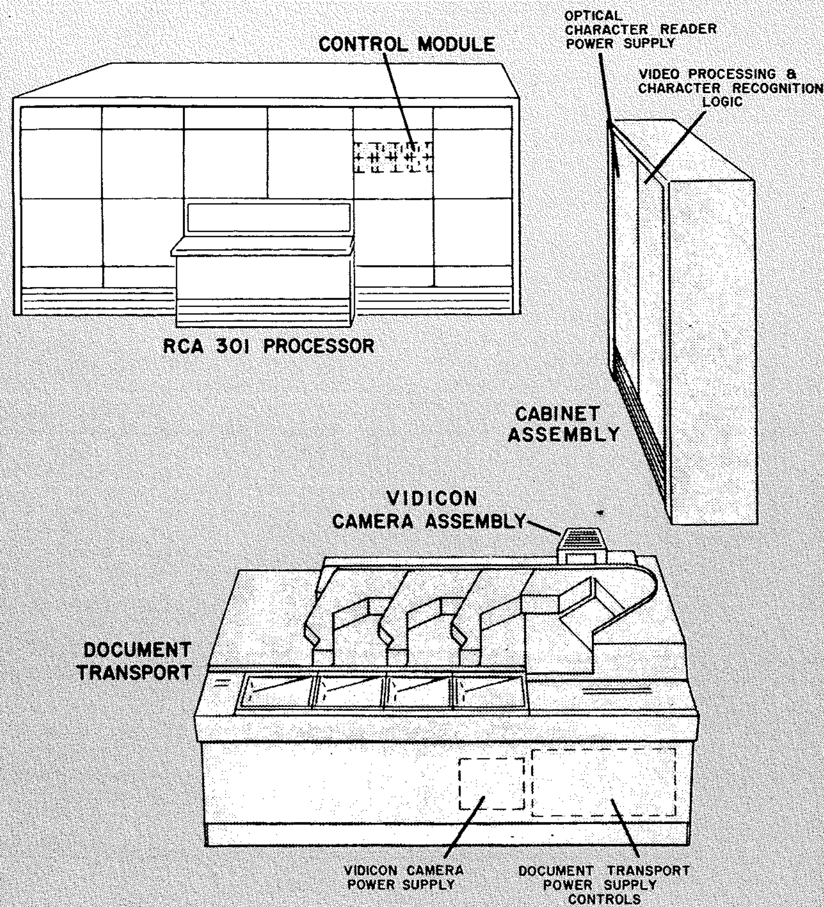

Fig. 2—Videoscan system.

VIDEOSCAN

. . . High-Speed Optical Reader for Computer Input

J. L. MILLER, Mgr. and **S. KLEIN, Ldr.***

Optical Character Reading Devices — *EDP Advanced Development*

Electronic Data Processing

Camden, N. J.

Videoscan is an optical character reader initially designed for RCA 301 computer input (on-line), using an RCA vidicon and providing a maximum tolerance of printed-character variations. It reads and converts to computer language a set of stylized numeric characters at a peak rate of 1,500 characters/sec—in the application described here, the numerals 0 through 9, and the symbols period, dash, asterisk, and dollar-sign. Its primary application is to high-volume accounting operations, where large volumes of data are generated by the computer that might be returned to the system as input. Videoscan, therefore, reads "turn-around documents"—i.e., data documents from the high-speed printer, which can both be easily read by humans and, through Videoscan, used as high-speed computer input. The experience gained in developing this product-line equipment is applicable to future generations of more-sophisticated optical character readers.

THE ever-increasing speed of data processing equipment requires that peripheral devices keep pace in order to have efficient operation. The slower speeds of key-punching cards, paper tape or other similar input media, with their inherent possibility of errors, seem inconsistent with today's nanosecond computers. This is especially true in applications involving generation of large volumes of data as output and its subsequent return for re-entry into the data processor. One solution is the generation of a turn-around document which is prepared at high speed by the computer printer and is subsequently read back into the system. This approach is especially applicable when periodic, high-volume billing is involved, such as insurance company premiums, utility bills, magazine subscriptions, and so on.

Magnetic-ink character recognition (MICR) is the approach being used in U. S. banking applications, which requires special inks to print characters in prescribed patterns. This system, however, requires costly printing techniques and produces characters that are not easy for human recognition.

EDP Engineering initiated a project to develop a computer input device that could recognize characters prepared by a computer high-speed printer, and be read easily by humans. (Work was already in progress in DEP on a *Multi-Font Reading Machine.*[1])

In the initial EDP effort, an array of

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* This work was done while Mr. Klein was with EDP; he is currently Leader, Tracking Design, DEP Aerospace Systems Division, Burlington, Mass.

Fig. 3—Vidicon scanning.

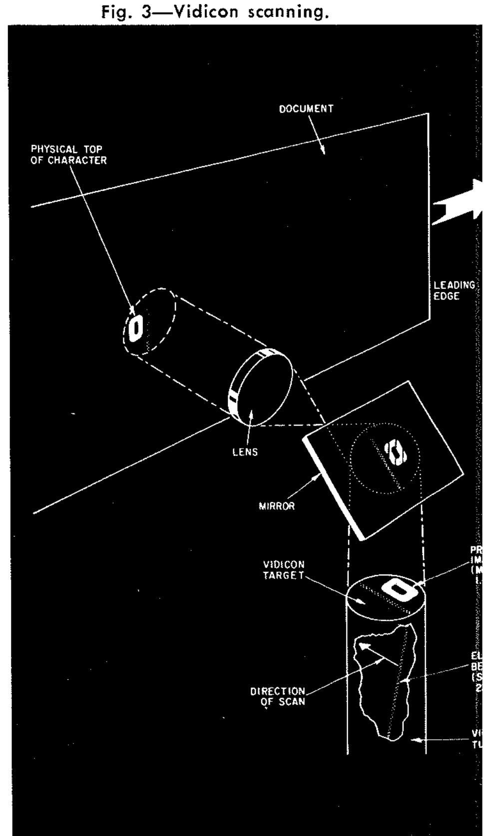


photo diodes was used to scan single lines sequentially on a printed page. The mask matching approach was used in which a scanned character image was stored in a memory and compared with a stored vocabulary for best match. Mask matching was abandoned because of lack of pick up and memory resolution. Increasing the resolution of the memory was costly, and the system was relatively intolerant of character distortion due to the method of centering the image in the digital memory.

At this time, elements of the DEP approach and the experience gained in the work done by EDP were combined and the RCA Videoscan was developed.

GENERAL DESCRIPTION

The RCA Videoscan was designed as an input device for the RCA 301 and subsequent computer systems. It was designed to scan and read one line per document pass and convert to computer language one set of stylized numeric characters. This is possible inasmuch as the majority of input data is numeric, or can be converted to numerics, such as account numbers, and so on. The character set chosen (Fig. 1) consists of the numbers *0* through *9* and four special symbols, the period, dash, asterisk, and dollar sign.

The equipment consists of a document transport, vidicon camera pick-up device, recognition logic rack, and a control module (Fig. 2). The document transport selects the document to be scanned and guides it past the vidicon camera at a rate of 750 or 1500 documents/min, depending on the size of the document. The system scans, recognizes, and converts to digital-code characters at a peak rate of 1,500 characters/sec.

MODES OF OPERATION

One of three modes of operation can be selected at the transport control panel: 1) *remote*, or on-line, operation (the equipment is controlled by the computer); 2) *local*, or off-line, operation, in which the equipment can be operated independently of the computer (for testing, maintenance, and initial set-up of the reader); and 3) *off-line select*, in which the scanner performs a sort operation controlled by a designated symbol.

TRANSPORT

Documents to be scanned are guided past the vidicon camera at a constant linear speed of 150 inches/sec. They are then deposited in one of two accept pockets or, if no accept signal is received, into the rerun pocket. Documents varying in size from 4 inches to 8½ inches long are handled at a rate of 750 per minute with a 12-inch leading-edge-to-leading-edge pitch, and documents varying in size from 2½ inches to 4 inches long are handled at a rate of 1,500 per minute with a 6-inch leading-edge-to-leading-edge pitch.

As the documents pass the vidicon camera, a single line of characters is scanned sequentially, beginning with the right-most character and ending with the last character of the scanned line.

SCANNER AND VIDEO PROCESSING

The RCA Videoscan, as the name implies, uses the vidicon tube as an optical transducer to translate the varying document reflectances into electrical signals that are used to identify the characters. Because continuous horizontal motion of a document is mechanically simpler than interrupted motion, scanning is done "on-the-fly" with a single line being traced by the electron beam on the face of the vidicon (Fig. 3). The horizontal dimension of each character is presented to the scanner by the motion of the document past the scanning beam. At the noted transport speed, a nominal character is scanned 10 times; 4 scans occur during the gap between successive characters. The scanning rate is approximately 22 kc with 40-μsec active scan time and 6.6-μsec blanking.

The vidicon tube was chosen for this application because of its reliability and ability to operate with a high-intensity light source, which minimizes variations caused by ambient light and simplifies the mechanical design of the camera assembly and transport.

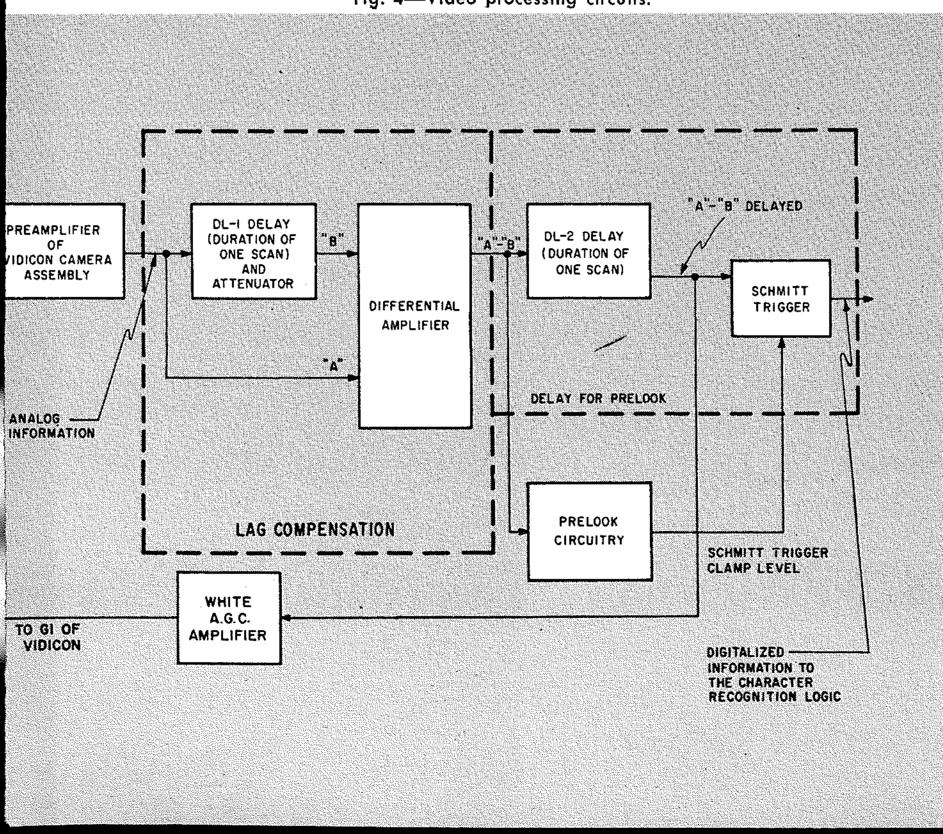
A disadvantage of the vidicon is its inherent lag, or sticking, characteristic, which causes horizontal character smear. Videoscan eliminates this by: 1) increasing vidicon target thickness, and 2) utilizing cancellation to do away with the major component of lag.

The cancelling is accomplished by subtracting a percentage of the preceding scan *B* from the scan of interest *A* by the use of a delay line having an electrical length of one scan line and a differential amplifier (Fig. 4).

Varying character density creates a serious problem in character recognition. To relieve the problem, a pre-look method is used to optimize the decision as to whether a segment is black (a character) or white (background). The pre-look is accomplished by delaying the lag-corrected video signal one scan line and adjusting the DC level at the Schmitt trigger circuit according to the peak amplitude of the video signal (Fig. 4). The Schmitt trigger converts the video signal to standard RCA 301 logic levels. If a lightly printed character is present, the decision between black and white information in the video signal will be close to the white level; if a dark character is present, with the inherent possibility of ink splatter and resulting noise, the decision level will be shifted towards black. In this way, each scan is optimized, and variations in density are corrected from scan to scan.

A white-signal automatic gain control (AGC) ensures a constant blanking to white amplitude input to the Schmitt trigger. This circuit adjusts the vidicon bias to compensate for changes in light source, document background, video circuits, vidicon tube, and so on.

Fig. 4—Video processing circuits.



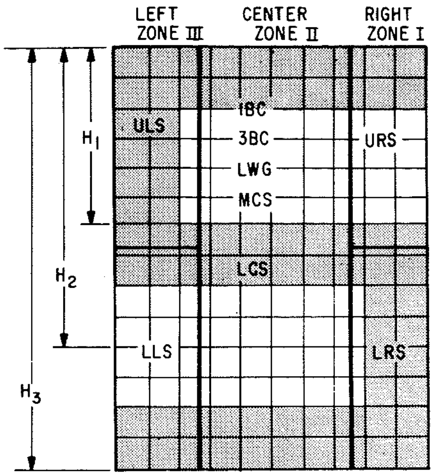


Fig. 5—Features of a character. (See Fig. 7 caption for glossary of abbreviations.)

RECOGNITION

The approach in designing Videoscan was to solve the basic systems problem of the turn-around document application. That is, it was realized that the quality of copy obtained from computer high-speed, electromechanical printers was at its optimum, and that the reader had to be designed to read the characteristic mutilations associated with each type of printer.

Drum and stylus types of printers were considered. The drum type is presently used in RCA computer systems. Some of the characteristic print distortions of these printers include:

1) tops or bottoms of characters missing;
2) poor vertical registration of characters;
3) variation in print (ink) density and line thickness;
4) vertical smear;
5) skew;
6) horizontal size variation; and
7) printing voids and extraneous noise (ink splatter in white areas)

Considering these printing problems, it was felt that a machine with feature-detection ability would provide the greatest flexibility and reading accuracy, and the widest tolerances in print quality.

In Videoscan, care was taken to avoid those features which were unreliable when considering a drum-type printer. Maximum emphasis was placed on vertical strokes and those portions of the character near the horizonal center line. A stylized font (RCA N-2) was chosen to take full advantage of the latter characteristics (Fig. 1).

Identification is accomplished through character zoning and by identifying features within specific zones. Fig. 5 shows the zoning and location of features for a nominal character. The presence of black of the correct shape in a zone indicates the presence of the specified feature. At least one feature difference exists between each character and all other characters of the set shown in Fig. 1.

As shown in Fig. 6, the quantized video from the video processor is fed to a pulse-width discriminator that removes video, or noise, that is less than a resolution element. The video is then clocked into the initial shift register. The start-character detector recognizes the presence of a character by the condition of video present in two consecutive scan lines. If video is not detected in the second scan line, the start-character detector resets the entire system.

The system performs horizontal integration by placing video from successive scans in the same shift register. As a result, no decision is made from information in only one scan line. Horizontal integration makes the unit relatively insensitive to edge irregularity, and greatly improves the amount of character skew that can be tolerated in a limited resolution system.

As indicated in Fig. 5, the presence of an *upper* or *lower stroke* is detected in Zone I, the right-hand portion of the character. The presence of a *medium stroke, long stroke, black crossing,* or *long white gap* is detected in Zone II, the center portion of the character. The presence of an *upper* or *lower stroke* is detected in Zone III, the left-hand portion of the character. Symbol detection requires classification of the character in three height categories.

The truth table (Fig. 7) illustrates where, in scanning, strokes must or must not be detected in zones of a specific character of the RCA N-2 Font.

VARIATION COMPENSATION

An asynchronous system of zoning was implemented to compensate for variations in character width, stroke width, and document velocity.

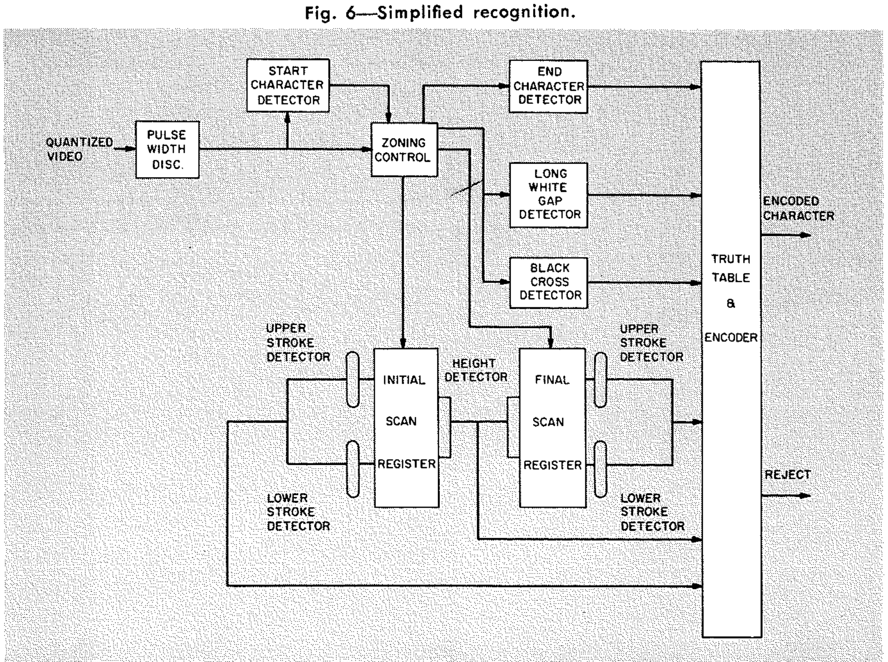
This was accomplished by clocking video from a nominal number of successive scans, corresponding to the nominal stroke width, into the Zone I shift register. If, at the end of the nominal Zone I, a *medium stroke* is detected by the on-the-fly *medium stroke* detector, the system continues to clock in video until the absence of a *medium stroke* is detected. This signifies the end of Zone I and the beginning of Zone II. The proposed video is then switched from the initial-scan register to the center-and-final-scan register.

In Zone II, horizontal integration is also performed with respect to *black crossings, long white gaps,* and *strokes.* The center-and-final shift register is emptied at the end of each scan in Zone II unless a stroke is detected. The switching sequence from Zone II to Zone III is accomplished by sensing the presence of a stroke after performing a nominal number of scans in Zone II.

The switching sequence from Zone III to determination of the end of character consists of performing a nominal number of scan lines corresponding to a minimum character width and continuing to scan, if video is present, until video is absent for one scan line. At the end of Zone III, the initial and final shift-registers are shifted until video is detected in the first position of either register. Majority gates detect the presence of *upper* and *lower strokes* in the Zone I and III registers. The height of the character is classified. A delayed, end-character pulse then interrogates the truth table (Fig. 7) and resets the system.

After identification, the character is encoded into RCA 301 computer code and sent to the control module in the

Fig. 6—Simplified recognition.



CHAR.	URS	LRS	MCS	LCS	ULS	LLS	LWG	IBC	3BC	VLZ	SLZ	GLZ	H1	H2	H3	H4
0	+	+		–			+		–	+						
0	+			–	+	+	+		–		+				+	
1	–			+					–		–	–				
2	+	–		–	–	+					+					
3	+		–		–	–	–				–				+	
3	+	+		–	–	–	–				–					
4	–	–	+			+		+			+					
4	–		+			+	+	+			+					
5	–	+		–	+	–		–								
5	–			–	+	–		–							+	
6	–		–		+	+									+	
6	–	+		–	+	+		–								
7	+	–	+						–		–				+	
8	+	+		–		+	–									
8	+			–	+	+	–				+				+	
9	+	+		–		–	–				+					
9	+		–		+	–	–								+	
•		–		–		–				–					–	
–		–		–		–		+	–	+			+			
$	–	+		+			–				+					
$	–	+		+			–					+				
*		–	+	–	+	–				+				+		
*		–	+	–	+					+	–			+		
M																+

– FEATURE MUST NOT BE PRESENT
+ FEATURE MUST BE PRESENT

Fig. 7—Truth table for RCA N-2 Font.

URS—upper right stroke
LRS—lower right stroke
MCS—medium center stroke (vertical)
LCS—long center stroke (vertical)
ULS—upper left stroke
LLS—lower left stroke
LWG—long white gap
1BC—one black crossing
3BC—three black crossings
VLZ—video left zone
SLZ—stroke left zone
GLZ—gap left zone
H1—height feature for indicated character
H2—height feature for indicated character
H3—height feature for indicated character
H4—height feature for indicated character

input-output portion of the data processor. If a set of features is detected and it is not a character specified by the truth table, an octal 57 is encoded and transmitted.

CONTROL MODULE

The control module controls the flow of information to the computer, one character at a time. When a character has been read and transmitted to the control module, a signal is generated to signify its presence and the character is read into the computer memory. Subsequent characters are read in until an *end of message* signal is generated by an *end of document*, *A-B* or *S-T* equality, or *reading window* termination.

After termination of a *read* instruction, the computer program performs the standard input-output operations, such as verification of data through comparison with a *check digit, accept* or *reject the document, select the appropriate transport accept pocket, write to tape,* and so on. Inasmuch as the transport is a continuous-feed device, as opposed to a demand feed, the *read* instruction for the following document must be staticized before the leading edge is detected at the reading position. This condition provides a fixed 80-msec read-and-compute time at the 750-document/min rate, and 40 msec at the 1,500 document/min rate. The control module is designed to operate in conjunction with processor simultaneous mode control, which extends the available processing time.

CONCLUSION

The Videoscan Optical Character Reader operates on-line in the RCA 301 computing system. The reader contains an RCA vidicon tube as the pick-up device and is designed to provide maximum tolerance of printer variations through the use of pre-look, asynchronous zoning, font design, feature detection, and automatic gain control. These techniques and the information gained in the development of the reader are applicable to future generations[2] of optical character readers.

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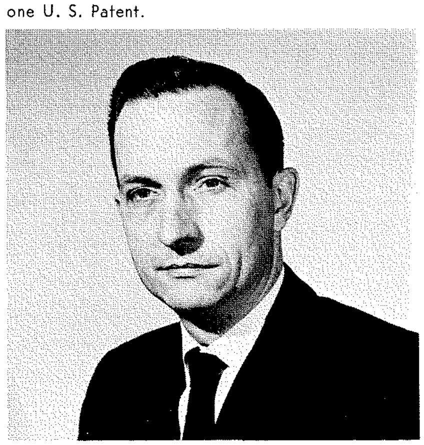
S. KLEIN received his BSEE from Drexel Institute of Technology in 1949 and joined the Advanced Development Group, Home Instruments Division, in the same year and participated in the development of UHF receivers until 1950, when he left RCA and joined the Manufacturers Engineering and Equipment Corporation, where he became involved in the development of specialized test equipment. He returned to RCA in 1955 and, in 1957, became Leader of the Synchronizer Group responsible for the displays and range trackers for the ASTRA Fire Control System. Other DEP responsibilities included development of an infrared image display device and character recognition for the DEP Electronic Reader. He transferred to the Advanced Development Group, EDP Engineering, as Leader of the group responsible for development of the numeric character reader in 1961. Currently, he is Leader of the engineering group responsible for the design of trackers for the LEM Radar, Aerospace Systems Division, Burlington, Mass.

JAMES L. MILLER received a BSEE from Iowa State College, Ames, Iowa, in 1948 and an MSEE from Drexel Institute of Technology this year. He joined the RCA Student Training Program following his graduation in 1948 and upon graduation from the training program, was assigned to the Component Parts Department. Transfer to the RCA Victor Home Instrument Division in 1953 brought responsibility for the design and development of TV amplifiers, monochrome and color video, color demodulators, a sonic 40-kc remote-control receiver and its application to a TV receiver. In 1960 he was transferred to EDP as a Leader, Design Engineering, responsible for tunnel diode logic circuits. Transfer, as Design Engineering Leader, to the Peripheral Products Section of EDP Engineering took place in 1961. In this capacity, he became responsible for the development of single-line, numeric optical character-recognition devices. He assumed responsibility for all OCR development and paper transports as Manager of OCR devices in 1963. He has six patent disclosures on file and is the holder of one U. S. Patent.



FIXED, ASSOCIATIVE MEMORY USING EVAPORATED ORGANIC DIODE ARRAYS

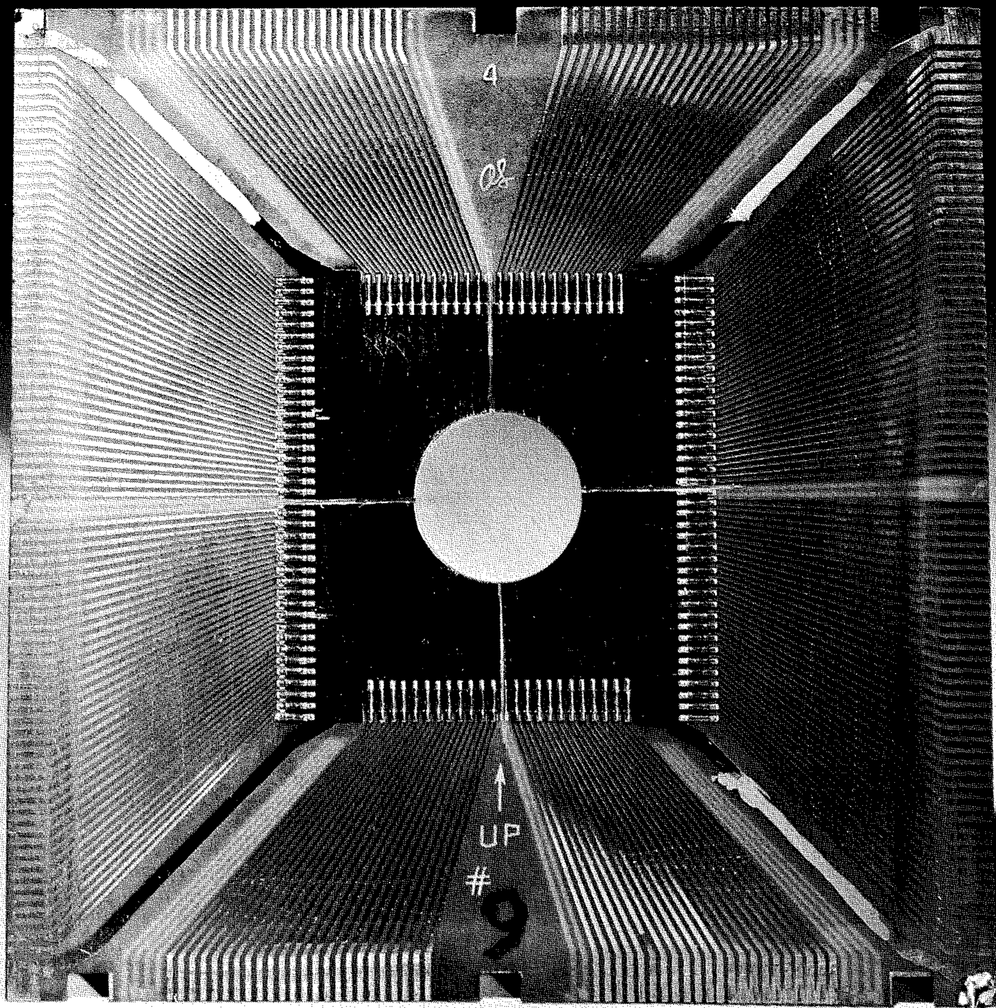
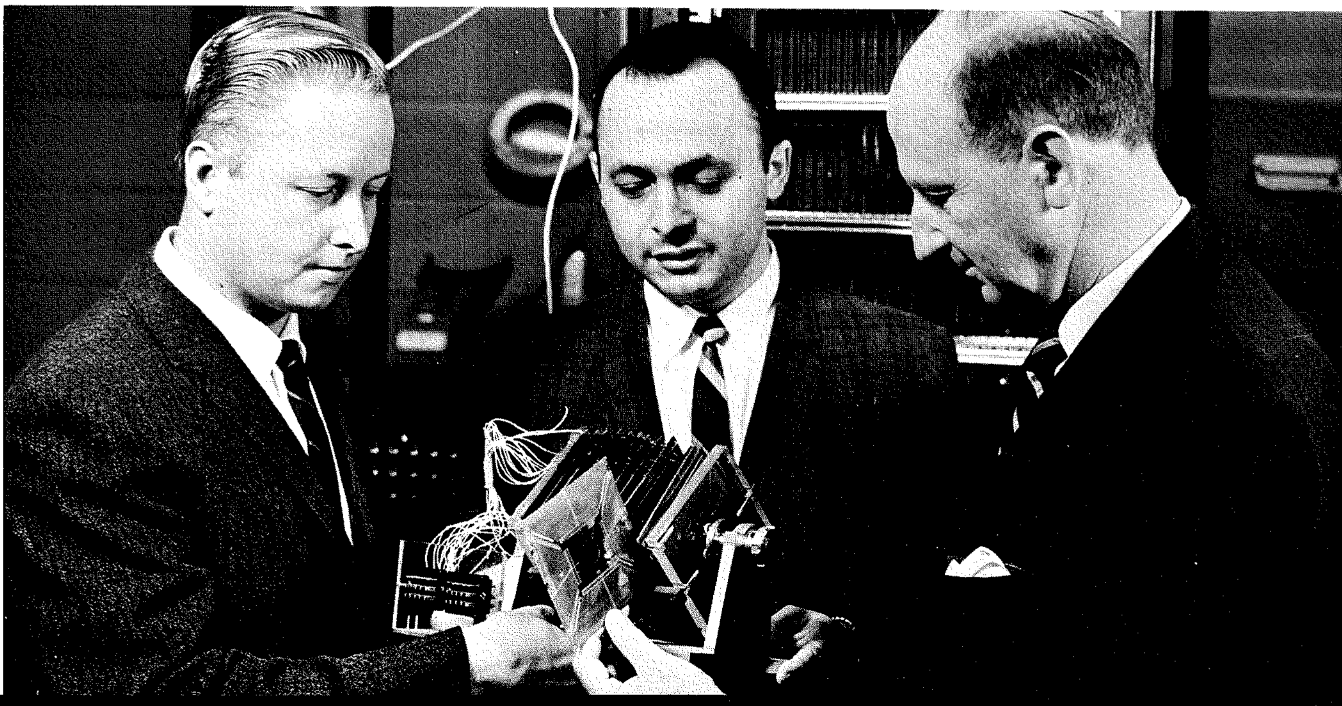


Fig. 1—Above: Evaporated organic diode card. Below: authors Howard Beelitz, Dr. Morton Lewin, and Dr. Jan Rajchman, who is here removing a diode card from a test memory stack. (Fig. 5).



Described herein are the associative properties of a symmetrical diode matrix operating as a fixed memory. All of the basic retrieval functions attributed to a general content-addressed memory, including multiple-match resolution, can be accomplished with this type of array. Further, the retrieval of m words answering a given description always takes exactly 2m-1 memory cycles, independent of the number of bits per word or the number of words in the memory. Also covered are experiments with diode arrays—in particular, arrays of of diodes fabricated by vacuum deposition of organic films. Circuits are presented that operate as either memory drivers or as sense amplifiers, depending on external logic control. These are part of the electronic mechanization of an automatic interrogation routine which accomplishes the retrieval of stored information. The experiments discussed verify the associative nature of the symmetrical diode matrix and the efficiency of retrieval of the interrogation algorithm, and also demonstrate the operation of organic film diodes as digital elements.

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THE USE OF fixed or read-only memories to store permanent or semi-permanent data has been widely treated in the literature.[1] Associative or content-addressable memories, discussed more recently,[2] provide the important capability for rapid parallel searching and retrieval of stored information. A fixed, associative memory can be used in applications requiring storage of encyclopedic data which must be searched at very high speed. Library search files, language translators and medical diagnostic tables, as well as small stores such as code converters and computer program memories may be of this type.

A magnetic realization of a fixed, content-addressed memory was discussed by Goldberg and Green[3] in May 1961. An interrogation routine to resolve multiple responses in this type of file was described by Frei and Goldberg[4] in December 1961.

The work on which this paper is based began, first, with the realization that a symmetrical diode matrix exhibits the basic retrieval properties of an associative memory and, second, with the development of techniques to fabricate diode arrays by vacuum evaporation of organic films.[5] One result of the investigation, already published,[6] was a very efficient algorithm for retrieval of multiple "matches" from a file of this type.

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SYMMETRICAL DIODE MATRIX

Consider the diode array shown in Fig. 2. It is composed of w word lines (rows) and b pairs of bit lines (column pairs) and therefore stores w words, each b bits in length. At every row, column-pair intersection is a diode, one of whose terminals is connected to the word line. A *0* is stored by connecting the other terminal of the diode to the right column of the pair. Connecting the diode to the left column indicates a *1* stored. Thus, the pattern of connections determines the information stored in the array. Every row is returned, through a resistor R, to a common voltage source V. For sufficiently large R and V, it sees a relatively constant current source looking into R. Each of the columns is terminated with either a driver or a sense amplifier. A given column-pair (bit) is driven with a *0* if the left column is grounded while the right column is connected to a voltage source E_I. Alternatively, one drives a *1* by reversing these conditions. Thus, pairs of bit lines are always driven with complementary signals. The sense amplifiers may be either voltage or current amplifiers, both of which are illustrated in Fig. 2. R_T may be considered as the input impedance of a voltage amplifier. The voltage V_d to which the input of a current amplifier is returned is the maximum forward drop across a memory diode conducting a current V/R. A positive sensed voltage v or a positive sensed current i indicates a *1* sense signal. No sensed voltage or current denotes a *0*. To keep the discussion general, assume each sense signal is amplified by a separate sense amplifier (two per column-pair). Under some conditions a single sense amplifier per sensed digit may be adequate. A

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DR. MORTON H. LEWIN received the BS, MS and PhD degrees in Electrical Engineering from Princeton University in 1957, 1958 and 1960, respectively. From 1955 to 1958 he worked at the Plasma Physics Laboratory, Forrestal Research Center, Princeton, N. J., where he was engaged in design of control and timing circuitry associated with the early Stellarator machines. Since June 1958, Dr. Lewin has been a Member of the Technical Staff at RCA Laboratories where he has been working on digital applications of new solid-state devices, notably the avalanche transistor, the tunnel diode and evaporated film elements. His current interests relate to information storage and retrieval with content addressable memories. Dr. Lewin is a Member of the Institute of Electrical and Electronic Engineers, and Sigma Xi. He is the author of several papers.

DR. JAN A. RAJCHMAN, Director, of the Computer Research Laboratory, RCA Laboratories, Princeton, N. J. developed the magnetic core memory system that is now the standard information-storage device in modern computers, and is responsible for pioneering contributions to the development of the electron multiplier tube. Dr. Rajchman received the Diploma E.E. (equivalent to an MSEE) in 1934 and a Doctor of Science degree in 1938 from the Swiss Federal Institute of Technology. His entire professional career has been with RCA. A student engineer at Camden during the summer of 1935, he became a research engineer in 1936. In 1942, he was transferred to the RCA Laboratories in Princeton. He became Associate Director, Systems Research Laboratory, in 1959. He assumed his present position in September 1961. His first field of work was electron optics. During World War II, he was among the first to apply electronics to computers. Later, he worked on the betatron. After the war he resumed work on computers and developed the selectron, and shortly thereafter, the magnetic core memory. He contributed many magnetic switching circuits, the transfluxor, the magnetic plate memory, and magnetically controlled electro-luminescent display panels. Dr. Rajchman is co-recipient of the 1947 Levy Medal of the Franklin Institute for his work on the betatron. He received the Liebmann Memorial Prize for the year 1960 for his contributions to the development of magnetic devices for information processing. Dr. Rajchman is a holder of more than 90 U.S. Patents and the author of many technical papers. He is a Fellow of the IEEE.

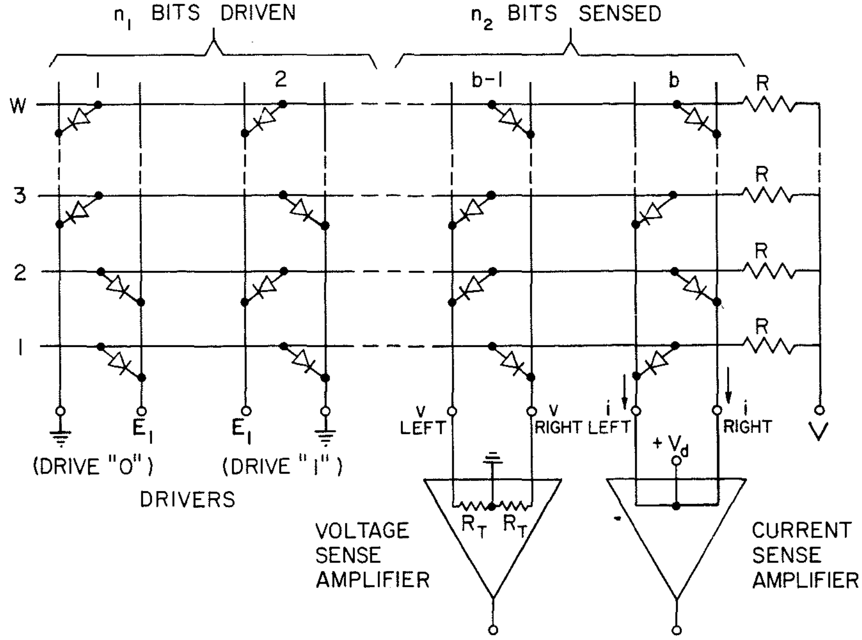


Fig. 2—Diode associative array.

difference amplifier for each pair of sensed columns can also be used.

One can divide the matrix into two parts: n_1 bits driven (inputs) and n_2 bits sensed (outputs), where $n_1+n_2=b$. In Fig. 2, the left portion is driven while the right portion is sensed. (Note that every row is the output terminal of an n_1-input diode *and* gate.) Assume, for a given set of inputs, only one row develops a relatively positive *(1)* voltage (i.e., it is selected). All other rows are clamped to ground (inhibited) and each of their currents V/R is steered to ground through at least one conducting diode connected to a grounded column wire. Those sensed columns which are coupled via diodes to the selected row will also be driven positive. Alternatively, one can say that the V/R current for the selected word is steered to split among those of its diodes which are connected to sensed columns. Note that each sensed column is the output terminal of a diode *or* gate. The number of inputs to the gate whose output terminal is the left (right) column is equal to the number of words which store a *1 (0)* in that bit position. Thus, the pattern of sensed voltages or currents will correspond to the pattern of diode connections between the selected row and sensed columns. Such an arrangement can be used as a decoder-encoder combination or as a fixed memory. In the first case, one is translating from an n_1-bit code to an n_2-bit code. In the second case, the n_1 bits are the address of an n_2-*bit* word stored. More generally, this array can be used as a content-addressed memory as is explained below.

The important property of such a matrix is the symmetry or reversability involved. For example, one can reverse input and output roles (i.e., drive the bits on the right side and sense those on the left side) to obtain an n_2-bit to n_1-bit decoder-encoder. In fact, any column-pair can be either driven or sensed—that is, serve as an input or an output. Thus, in the general case, any arbitrary number of bits, scattered in any manner among the b bit positions, can be driven while the remaining bits are sensed. The fact that this yields a content-addressable memory can be made clear with a simple example. Suppose one asks for retrieval of all words (assume there is only one, to begin with) which answer the following specification: *0* in the 1st place, *1* in the 4th place, *1* in the 8th place, etc. All of the column-pairs in the positions designated above are driven with polarities corresponding to the specified bits (tag bits or descriptors). All unspecified digit line pairs (i.e., the 2nd, 3rd, 5th, etc.) are sensed. Thus, sensing a pair of columns corresponds to a *don't care* or ϕ specification for that bit. (The interrogation word for this case is $0\phi\phi1\phi\phi\phi1\phi\phi$ . . .) Clearly, for the most general associative memory, each pair of bit lines must be terminated in a combination driver-sense amplifier which can be switched between drive and sense in accordance with the specification for that bit in the interrogation word. Circuits developed for this purpose will be described later.

When the drivers and sense amplifiers are set up corresponding to the interrogation word given, the selected word line assumes a relatively positive voltage while all others remain nearer to ground potential. The pattern of sensed voltages or currents corresponds to the pattern of diode connections for the selected word, so that all the other bits in the word answering the description given are read out simultaneously.

MULTI-MATCH READOUT

More generally, more than one word is selected by a given specification and all must be read out in some ordered fashion. This problem is common to all physical realizations of associative memories. There are, broadly, two solutions to the problem. One involves incorporating, in the memory array, appropriate circuits to allow for sequential activation and readout of selected words. The other involves manipulation of the interrogation word, outside of the array, in such a manner that all selected words are isolated and read out in sequence. This latter method has proven very well suited for use with the diode matrix. An algorithm has been developed[6] which requires no modifications of the basic memory array and yet retrieves all selected words in less than two memory cycles per word. This is true, independent of the total number of words stored in the file and independent of the number of bits per word.

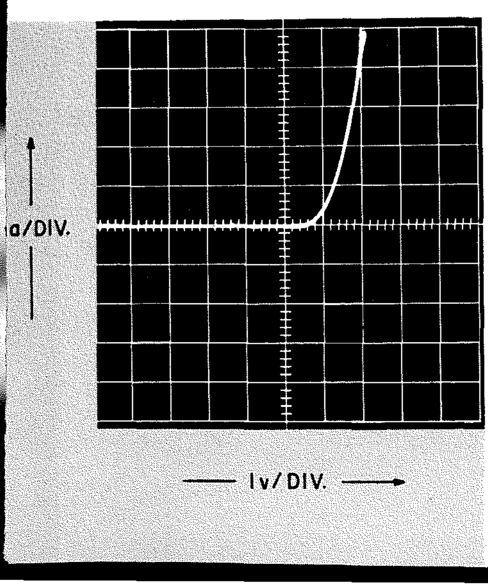
The interrogation algorithm relies on the fact that *two* columns per bit are available for sensing. If the memory is driven so that only unique selections occur, only one column per bit need be sensed, since the output signals of any column-pair will always be complementary (i.e., *0, 1* for a *0* stored; *1, 0* for a *1* stored). The first use of sensing both columns of a bit is simply to detect when *no* word stored answers the description given. If there are no words selected, all rows are clamped to ground. Thus, a *0, 0* detected at *any* sensed column-pair gives this indication immediately. If a multiple-selection is made, as is usually the case, more than one row assumes a relatively positive voltage. If all words selected (isolated) have the same bit in a given position being sensed, the sense signals for that bit are similar to those detected for a unique selection of one of these words. One can say that the sense signals are "reinforced" or stronger in the multiple-selection case. More often, however, some of the words selected have a *1* stored in a particular sensed position, while the others have a *0* stored there. In this case, *both* columns of that bit are driven positive, or carry a positive sense current (i.e. *1, 1* detected), since each is coupled through at least one diode to a selected row. One can say that an x has been sensed in this case.

The ability to detect the above conditions, coupled with the fact that any bit can be either driven or sensed, allows one to efficiently retrieve all words selected. Combination driver-sense amplifiers, controlled by external logic inputs, are used. The interrogation routine is based on the fact that, as one converts sensed-x bits to driven bits, smaller sets of words are selected. In this manner, we have, with appropriate external logic, made successive interrogations converting sense amplifiers (sensing x) to drivers and drivers to sense amplifiers so that all words originally selected are isolated and read out individually. The interrogation sequence is generated based on a set of rules by which the interrogation pattern for a given cycle depends on the pattern and the sensed results of the previous cycle. One effectively generates a "decision tree" in this manner.

This algorithm is described in detail in the paper[6] referred to earlier. Included in the paper is a detailed flow chart for generating the interrogation sequence, a comparison of this routine with other published work dealing with the same problem, a complete per-digit logic design for mechanizing the routine and a proof that retrieval of m words always takes exactly $2m-1$ memory cycles, independent of the number of words in the memory or the number of bits per word. Since the paper deals primarily with the logic of the routine, applicable to any physical realization which allows "column-pair sensing" and simultaneous activation of all selected word lines, no specific mention is made of fixed memories or diode matrices. (A cryogenic implementation is described only as an example.)

One point to note is that, while some physical realizations would require a word-driver per word to achieve simultaneous activation of all selected (or "matched") word lines, the diode array described above *automatically* furnishes this without the need of word-drivers. (i.e., every selected row develops a positive voltage which *directly* couples to sensed columns via its diode pattern.) This is a fundamental reason why the algorithm is particularly well-suited for a fixed memory configuration of the type discussed above.

Fig. 3—Copper phthalocyanine diode characteristic.



EVAPORATED DIODE ARRAYS

A large diode matrix serving as a fixed, associative memory is economically feasible only if sizeable arrays of diodes can be fabricated at sufficiently low cost. A new technique for constructing integrated arrays of thin-film diodes has recently been described.[5] It embodies vacuum evaporation of an organic semiconductor, copper phthalocyanine. Diodes fabricated by this technique were used experimentally to implement the associative memory concept considered here.

A multiple organic diode card is shown in Fig. 1. Each 4″ x 4″ x 0.020″ board holds 128 diodes which are distributed around the outline of the dark phthalocyanine inner square. All diodes have a common cathode, connection to which is made at any corner of the card. (Diode polarities for all of the experiments described are the reverse of those given in Fig. 1.) The card shown can be used to store one 128-bit word, with the common cathode conductor being a row wire of the matrix. A set of n such cards, completely interconnected, comprises an n-word, 128-bit-per-word, memory. Two etched wires per diode form the anode connection, "fanning out" to the card edge. These allow connection of a given diode anode to both of its associated column wires. Information can be written in by breaking the appropriate anode connections in any of a number of ways such as, for example, by punching a series of small holes in the card. The card pattern shown was chosen to allow a relatively small area for the evaporation of the diodes, in order to insure the desired uniformity of characteristics.

The static characteristic of a typical evaporated thin-film diode is shown in Fig. 3. With a diode area of 3.5 mm^2, the voltage drop is approximately 1.5 volts at a forward current of 2 ma. Its rectification ratio is approximately 10^5.

Each diode consists of a three-layer sandwich, the middle layer being copper phthalocyanine and the outer layers being metal anode and cathode electrodes. Since the diode is such a thin element, its equivalent parallel plate or "case" capacity is large, being typically, for the area given above, approximately 50 pf.

EXPERIMENTS

Peripheral Electronics

The circuit design of the peripheral electronics system which was constructed to exercise and test various embodiments of the diode associative memory was largely conventional (primarily using RCA 2N404 transistors). The apparatus consists of all the logic and the combination driver-sense amplifiers for implementing the search routine[6] for a memory word length of 10 bits. Display of retrieved words, memory cycle count and driven or sensed states, for each bit, are included.

The requirement of a combination driver-sense amplifier controlled by external logic inputs, resulted in a somewhat novel design. A schematic diagram of the circuit is indicated in Fig. 4. When in the drive state, it can furnish the memory with up to 0.5 amps at ground potential. This would allow the circuit to drive a 1,000-word (100-bit-per-word) diode associative array. It is also capable of detecting 10 μa of signal current when in the sense state and strobed (CP_4 is the strobe pulse). The circuit will switch between drive and sense, as demanded by the input signal f_i, in 0.5 μsec. The function table shown in Fig. 4 relates the circuit state (drive or sense) to the logic input states. Two such circuits are required per column pair.

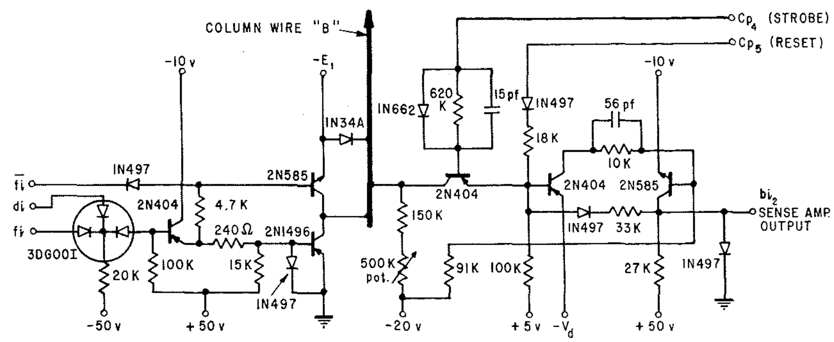
500-Bit Diode Matrix

A small, conventional-diode array, constructed as a 50-word, 10-bit-per-word manually-alterable memory, served as initial experimental verification of the basic idea of a diode associative memory and of the electronic mechanization of the interrogation routine. Various patterns of information were written into the array by manually changing the pattern of diode connections.

A number of tests were made with this matrix. These include the lexicographic ordering of the entire memory contents and a large number of searches using a wide variety of input descriptor patterns. (Descriptors are inserted using a bank of toggle switches.) For each test series, the interrogation routine can be manually stepped along and monitored or can proceed automatically at a maximum rate of 100 kc (10-μsec cycle time). The total number of cycles required for each retrieval was monitored by a counter and could be compared with the predicted count.

Organic Diode Array

Fig. 5 is a photograph of a stack of organic diode cards, each of the type shown in Fig. 1, which was successfully



DRIVER-SENSE AMPLIFIER FUNCTION TABLE, COLUMN "B"

fi	$\overline{fi}$	di	FUNCTION
0 v	-10 v	0 v	SENSE DURING STROBE PULSE
0 v	-10 v	-10 v	DRIVER PRESENTS A HIGH IMPEDANCE
-10 v	0 v	0 v	DRIVE "0"
-10 v	0 v	-10 v	DRIVE "1"

NOTE :- COLUMN "A" DRIVER-SENSE AMPLIFIER IS IDENTICAL BUT WITH $\overline{di}$ REPLACING di. THIS PROVIDES THE REQUIRED COMPLEMENTARY DRIVE.

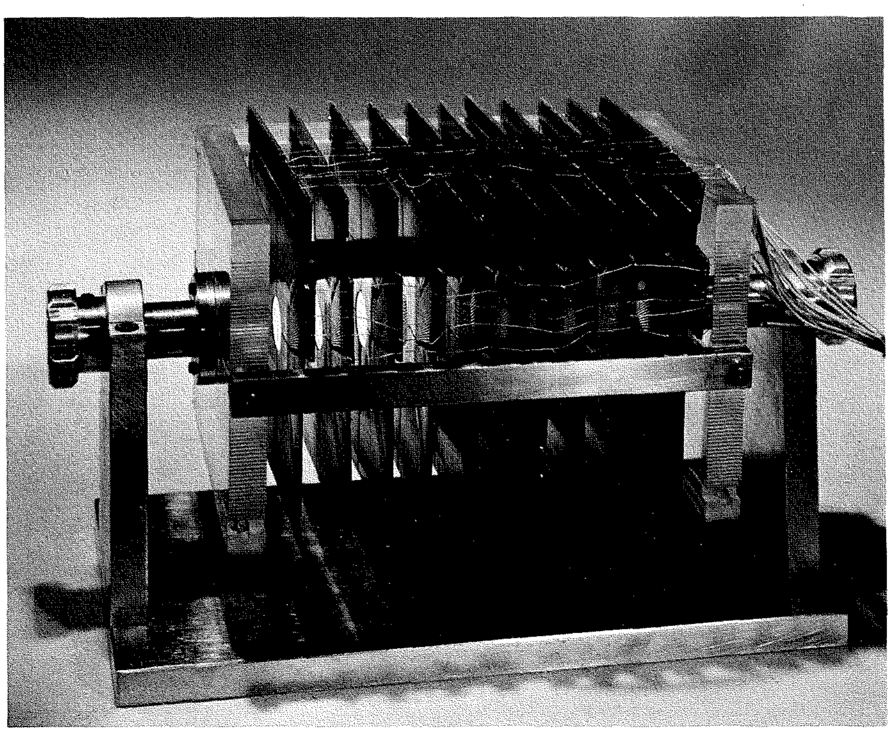
Fig. 4—Drive-sense amplifier circuit.

operated as a small test memory. Although each board contained 128 diodes, only 10 bits on each card were used for the tests because of the limited amount of peripheral electronics which was then available.

The diode cards are mounted in a metal frame with specially-designed "finger" connectors used for each card. Column wires running down the outside of the card stack are soldered to the finger connectors and provide the required card-to-card interconnection. The information stored is determined by the pattern of connections to these column wires. This allowed one to change the information stored without removing the cards and was convenient for the tests made.

Various search and retrieval tests were performed with the organic diode memory. In general, the experiments duplicated those performed with the conventional diode matrix. They demonstrated the feasibility of using thin-film organic diode arrays as digital elements.

Fig. 5—Organic diode test memory stack.



CONCLUSIONS

The purpose of this paper has been to explain the associative properties of a symmetrical diode matrix, including the applicability of a very efficient interrogation algorithm to resolve multiple-matches, and to describe experiments which verify these concepts and which, in addition, utilize arrays of new thin-film diodes. Clearly, the physical realization of this type of diode matrix can be in many forms and may well involve other diode array fabrication technologies, including those now developing in the semiconductor industry.

ACKNOWLEDGEMENTS

The authors wish to thank A. Sussman, who did the basic experiments which resulted in the evaporated, copper phthalocyanine diodes and who designed and fabricated the diode cards. We are also indebted to O. Kornehed, for assistance in peripheral circuit design, J. Schumacher, for measurements, on the organic diode parameters, J. Guarracini, for the design of the "finger" connectors and H. Schnitzler, who constructed the test equipment and assisted in many of the measurements.

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A VERSATILE TWO-PHASE MERCURY TUNNEL FOR GENERATION OF SUPERSONIC PLASMA STREAMS

This mercury plasma tunnel for the generation of supersonic low density plasma streams uses the two-phase (vapor-liquid) cycle of mercury for generating the flow and can employ either DC or RF excitation of the plasma stream. The tunnel provides continuous, high-velocity flow streams without large mechanical pumping facilities. Velocities of the order of mach 4 have been achieved at pressures down to 10^{-2}torr. The system provides supersonic plasma streams with easily controllable parameters over a wide range of operation conditions.

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One of the major problems encountered in the operation of a high-velocity, low-density plasma tunnel is the requirement for vacuum pumping facilities with sufficient gas handling capabilities at the low pressures desired. With conventional mechanical pumping techniques, the cost and bulk of such facilities very often proves to be prohibitive. A technique which alleviates the problem is to employ a two-phase (either vapor-solid or vapor-liquid) system for the flow generation. In such a system, the test gas flowing through the nozzle in the tunnel is condensed in the low pressure section by external cooling.

Several such applications of *cryogenic pumping* for plasma flow devices have been reported recently in the literature[1,2] and with proper selection of the fluid cycle such a two-phase system can offer many advantages over a conventional flow system utilizing vacuum pumps. In a recent experimental study of plasma flow generation, the two-phase mercury flow system described herein has been developed into a useful research facility.

CHOICE OF MERCURY AS THE TEST FLUID

Mercury has been chosen as the test fluid in the present investigation because it exhibits several useful properties for this purpose. At room temperature, the vapor pressure of mercury is of the order of 10^{-3}torr, so that tap water can conveniently be used as the coolant in the condenser section of the tunnel. Pressures up to 100torr can be generated by a mercury boiler at convenient temperatures ($\sim$260°C) in the high pressure region of the tunnel so that nozzle pressure ratios (*inlet/outlet*) of the order of 10^4 can readily be obtained. On the basis of simple isentropic flow calculations[3] (neglecting boundary layer effects) this indicates the possibility of achieving flow streams with velocities of the order of mach 6 and static pressures in the low micron range with very small (mechanical) pumping capacity.

The use of the vapor-liquid rather than the vapor-solid two-phase cycle has the advantage that the efficiency of the cryogenic pump remains constant since the liquid drains off and may be recycled, whereas the solid builds up a thermal insulation layer over the surface of the condenser and limits the time of operation.

Mercury offers an additional advantage from the point of view of plasma generation in the supersonic stream. It is known that the velocity of sound in a gas of molecular weight M, varies approximately as $(M)^{-1/2}$. This means that for a given mach number and temperature, the absolute velocity of a heavy gas will be less than that of a light gas. Conversely, at a given temperature, the mach number in a heavy gas is greater than that in a light gas with the same absolute velocity. For aerodynamic similitude, the mach number is the essential velocity parameter, but for electrical excitation of a plasma it is the *absolute velocity*—which is important, since it determines the time the gas spends in the region of electrical excitation. For this reason it is advantageous to use a heavy gas such as mercury ($M = 200$) instead of a lighter one such as nitrogen ($M = 28$) or argon ($M = 40$) in the generation of supersonic plasma streams.

In addition, mercury is a substance which can be readily handled in glass or metal systems and which has well-known and tabulated properties (vapor pressure, spectroscopic data, etc.)

APPARATUS

A schematic diagram of the tunnel is shown in Fig. 1 and photographs of it are shown in Figs. 2 and 3. This system has many design features in common with the single-phase RF excited tunnel described recently by the author.[4] The basic flow system is constructed from standard sections of Pyrex (double-tough) glass, with the test section of the tunnel being in the form of a six-arm "cross" of 4-inch-diameter tubing. As in the single-phase system, a variety of nozzles of conical shape can be employed. These are made of either Pyrex or Vycor and are connected to the test section through a standard ground-cone joint in a stainless steel plate so that they can be readily interchanged. As shown in Fig. 1 the stainless steel plate is water cooled to prevent breakage of the nozzle assembly by thermal expansion. This metal plate

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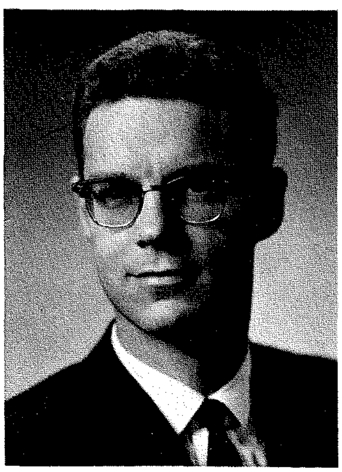

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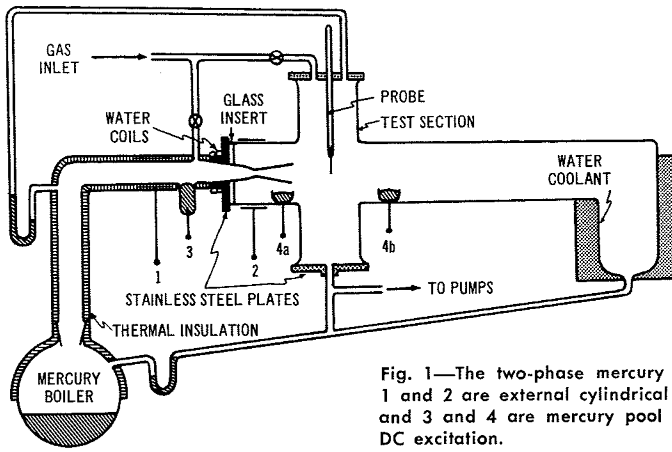


Fig. 1—The two-phase mercury tunnel. Items 1 and 2 are external cylindrical RF electrodes and 3 and 4 are mercury pool electrodes for DC excitation.

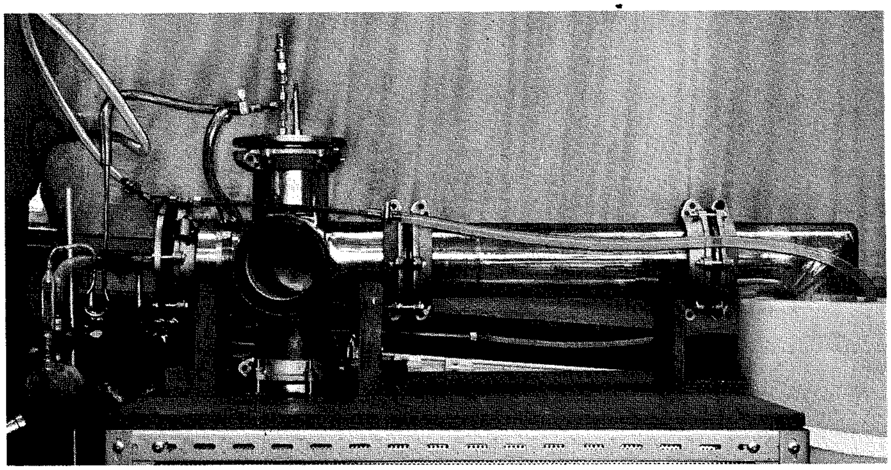


Fig. 2—General view of the apparatus.

is shielded from the plasma in the test section with a glass insert as shown. This was found necessary to prevent contamination of the mercury plasma by impurities evolved at the metal surface under the influence of the intense electrical discharge in this region of the tunnel.

The stainless steel plates at the top and bottom of the test section were left ungrounded so that spurious discharges are not generated in the apparatus. These plates contain the various couplings required for the insertion of probes into the stream and for pumping and gas inlet lines, as shown in Fig. 1. Pyrex plates are employed on the front and back of the test section to allow optical and microwave observation of the supersonic plasma stream, over a distance of approximately 10 cm downstream from the nozzle. To prevent mercury condensation, these windows are heated externally by a flow of hot air from a commercial air gun.

The residual gas pressure in the tunnel is maintained at the low micron level by a small vacuum pumping system (2-inch mercury diffusion pump and 2-cfm mechanical pump). The mercury boiler can be heated electrically or with the aid of a gas burner and is capable of providing steady vapor pressures up to several centimeters of mercury. The insulated glass walls (Fig. 1) minimize the condensation of the mercury vapor before it reaches the nozzle.

In the present system, two methods may be used for generating the plasma in the mercury-vapor stream. The first of these utilizes electrodeless RF excitation and is identical with the method described for the single-phase tunnel.[4,5] The external cylindrical electrodes (*1* and *2*) used for the RF excitation are shown in Fig. 1. The RF generator utilized has a rated power output of 1 kw at a frequency of 13.5 Mc.

The tunnel can also be used with DC arc-generation of the plasma stream. The positioning of the electrodes (*3* and *4*) used for this purpose is also shown in Fig. 1. The electrodes are actually mercury pools in glass containers connected to the external power supply by glass-sheathed conductors. The use of mercury pools eliminates the possibility of electrode material contaminating the plasma stream and thus removes one of the major disadvantages involved in the use of any DC plasma arc jet.

In the original version of the tunnel, the DC excitation was obtained by a pair of electrodes located at the position *3* in Fig. 1. These electrodes were positioned so that the arc was generated diametrically across the mercury flow immediately upstream from the nozzle. This method provides a reasonably uniform excitation of the plasma stream and supplies sufficient energy to the mercury vapor to prevent condensation during expansion through the nozzle. Thus supplementary superheating of the vapor[2] is not required.

Although this method of excitation worked well, a considerable increase in the plasma ionization was achieved by placing one of the electrodes (the anode) downstream from the nozzle in the test section. This arrangement forces the arc to pass through the nozzle and hence provides continuous excitation of the flow right up to its entry into the test section. This mode of operation is identical in principle to the RF techniques already described by the author[4,5] and is similar to the constricted arc discharge recently reported by Shepard and Watson.[6]

By placing the anode (*4a*) upstream from the exit of the protruding nozzle, stray excitation in the test section is minimized. If the anode is positioned further downstream (e.g. at *4b* in Fig. 1) the arc can be utilized to heat the flow throughout the entire test section if desired. This method has been used to provide increased luminosity (and ionization) at greater distances from the nozzle than would be obtained with the anode at position *4a*. The DC power supply employed in the apparatus can supply power inputs of the order of 1 kw.

APPLICATIONS

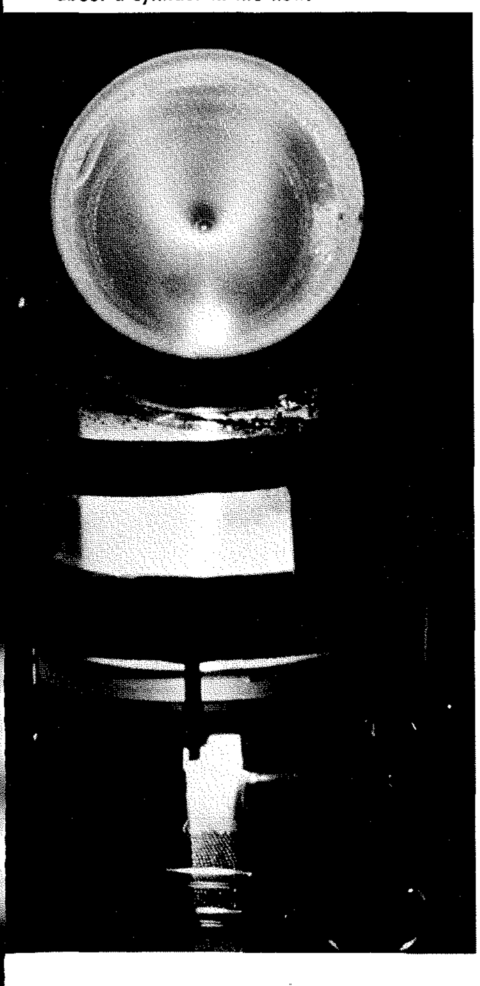
Although the tunnel is somewhat limited in its aerodynamic applications, since it employs only mercury vapor as the flow gas, there are many investigations which can be undertaken in this apparatus. To date, the tunnel has been used extensively to study the interaction of electromagnetic waves (microwaves) with supersonic plasma flow fields and it has been found to be a very reliable and versatile facility.

The tunnel has proven its capability for sustained operation over extended periods of time. The apparatus has not shown any serious limitations in this respect even after being operated continuously for periods of a few hours. In fact, after the initial pump-down and degassing period it is possible to run the sys-isolated from the external vacuum pumping system.

This tunnel also provides a supersonic flow jet of easily controllable parameters. The stagnation pressure is readily regulated by adjusting the boiler temperature and the test section pressure is controlled by the temperature of the condenser surface hence a wide range of mass flow rates can be achieved. Additional control over the stream characteristics is obtained by admitting argon (or any other inert gas) to the system through the needle valves shown in Fig. 1. This gas can be introduced in either the high or low pressure section of the tunnel as desired. The present facility has been operated at velocities up to mach 4 (as determined by the shock angle visible about a wedge in the flow), and at static stream pressures down to about 10^{-2}torr. Typical stream diameters are in the range from 1 to 3 cm and, in general, the visible portion of the jet extends the full length of the tunnel (about 1 meter).

The two methods of plasma excitation (RF and DC) have been applied separately and simultaneously at power levels in the 1-to-2-kw range. Using this feature of the system it is possible to examine the relative efficiencies of the two methods for exciting the plasma stream. Although the dependence on the many parameters has not yet been studied in detail, it has been found that under typical conditions, the DC power (the arc current-voltage product) to generate a given plasma is of the order of 25% of the RF power (recorded at the output of the transmitter) required to produce a similar stream. In view of the nonideal RF matching conditions and the large amounts of radiated RF signal, this result seems quite reasonable. The RF excitation, however, has the advantage of producing a much more steady plasma since in the DC mode, the arc often exhibits fluctuations arising from the movement of the arc spots over the mercury pools. (This can be improved with some sacrifice to the purity of the plasma stream by introducing metal "hold" electrodes in the system.)

Fig. 3—Close-up of the tunnel in operation, showing the supersonic flow (approximately mach 3.5 at a pressure of about 0.05 torr) about a cylinder in the flow.



At the low power levels employed in the present system the gas (and ion) temperatures of the stream are only of the order of 700 to 800°K. Microwave and probe studies of the jets show that electron temperatures in excess of 10^4°K are obtainable and that typical electron densities are $10^{13}/cm^3$ at the nozzle exit. Higher power levels can be employed, but this would require additional cooling of the nozzle assembly.

In addition to its application as a research facility, the two-phase mercury tunnel is also an excellent tool for laboratory demonstrations of the properties of supersonic flow fields. Since the luminosity of the jet depends on the local pressure (density) in the stream, the details of the flow are continuously visible. Hence, the effects of nozzle expansion, boundary layers and flow about bodies, etc. can be observed over a wide range of conditions, without the aid of additional equipment such as a schlieren system.

The tunnel shown in Fig. 4 was specifically constructed as a simple device for observing the structure of supersonic streams. Since this tunnel employs standard glass components (and hence, requires a minimum of glass blowing) and can be operated by a 110-volt-DC source supplying 2 or 3 amperes, it is very simple to assemble and operate in any laboratory. The test section is detachable and can be easily modified to allow the introduction of Langmuir probes or obstacles into the supersonic jet. With discharge currents of the order of a few amperes a safe operating-temperature for the glass can be maintained by air cooling of the condenser, so water plumbing is not required. Heat can be supplied to the boiler by an ordinary bunsen burner and sufficient pressure for operation can be maintained even without any thermal insulation on the high temperature section of the tunnel.

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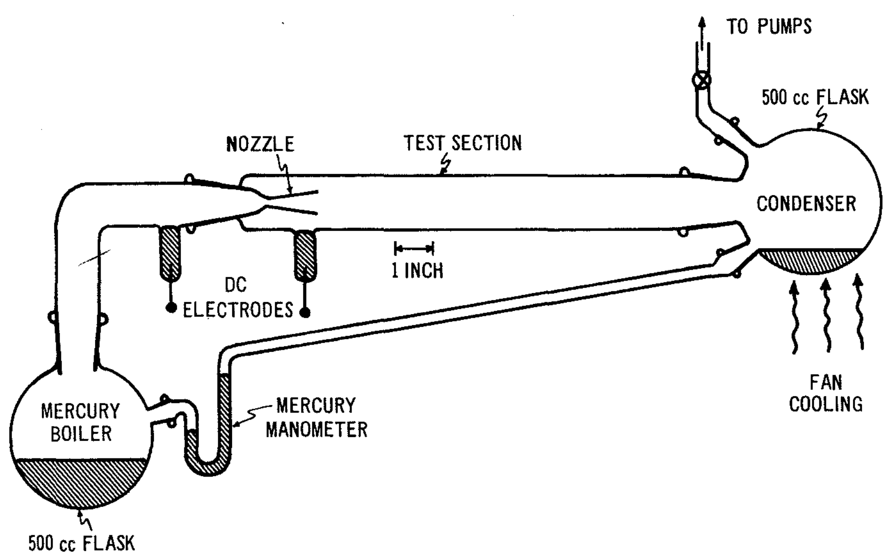
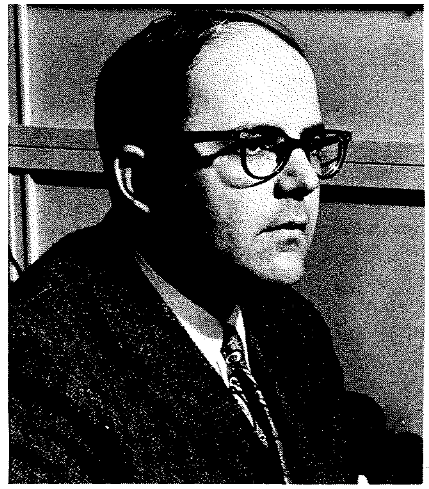


Fig. 4—Simple two-phase mercury tunnel for flow-field studies.

A COMPARISON OF SOLAR-CELL POWER SUPPLIES WITH RADIOISOTOPE-POWERED THERMAL GENERATORS FOR SPACECRAFT



SEYMOUR H. WINKLER received a BSME cum laude, from the College of the City of New York in 1947 and an MSME from Purdue University in 1952. He has taken further graduate work towards his PhD in Nuclear Engineering. From 1947 to 1951, he was an instructor at Purdue University. In 1951, he joined Kaman Aircraft Corporation, where he developed helicopter systems. In 1955, he joined Young Development Labs, where he developed filament-wound plastic rockets. Mr. Winkler joined the Astro-Electronics Division in 1958. He was in charge of solar power systems development for the TIROS series, RELAY, NIMBUS, and RANGER Systems; has designed solar simulators for space chambers and solar cells. Mr. Winkler has also redesigned space storage batteries for greater reliability and lower weight. Since 1962 he has been responsible for the study, design and development of RCA's high-temperature radioisotope thermoelectric generator, as well as studies in the thermionic conversion field, and is now Leader, Advanced Space Power Systems. He directed the RCA study and proposal effort on the LEM electrical power subsystem. Mr. Winkler has published papers and contributed to books in the space power field. He is a member of the AIAA, the National Committee for Standardization of Solar Cell Measurements, and Pi Tau Sigma. He is also a registered Professional Engineer in the State of New York.

As part of its effort in developing spacecraft systems, subsystems, and components, the DEP Astro-Electronics Division has been greatly concerned with the design and development of power systems for both manned and unmanned spacecraft. Until recently, the only practical means of developing long-lived power in the 1-watt to 1-kilowatt range has been with photovoltaic solar cells. However, nuclear reactors and radioisotope energy sources are being developed which will compete with and extend beyond the capabilities of solar-cell devices. This discussion will compare solar-cell and radioisotope power systems of 1 kilowatt or less, drawing on AED's experience with spacecraft and spacecraft subsystems to provide the comparison criteria. Most of the data is based on two phases of this experience: 1) the solar-cell systems that AED has developed, and 2) the isotope-powered thermoelectric generator that is now in the hardware development phase.

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BEFORE discussing the performance of a space power system, the performance criteria must be established. These criteria include: weight, cost, reliability, sensitivity to environment, volume, availability, safety, growth potential, ease of integration, pre-launch maintenance, post-launch ground processing, and (for manned spacecraft) endurance life between maintenance operations. The performance of space power systems must be judged in terms of the relative importance assigned to each of the above factors. For the early spacecraft, weight was the most important consideration, as the primary program limitations were the capabilities of the launch vehicles. Now, with the payload-weight capabilities of the rockets steadily increasing, cost and the other factors are becoming more significant. However, for the next several years, the weight limitation will still remain a critical factor in system selection; therefore, this discussion will concentrate on system weight comparison.

Some actual values for operating parameters of solar-cell and isotope power systems are described in the following paragraphs. The solar-cell arrays considered include those oriented normal to the sun's rays as well as the unoriented types (which have until now been more common). The isotope power systems considered have thermoelectric and thermionic energy converters. Except where noted, all values assigned to operating parameters are for systems currently within the state of the art. Improvements can be made in both the solar-cell and the isotope power system characteristics, and the values presented are conservative.

In this discussion, several values of power-to-weight ratios in the power range of 25 to 75 watts have been determined for the solar-cell systems as well as for the radioisotope thermoelectric systems. Since the power-to-weight ratios have a distinct dependence on power (especially in the isotope-powered units) comparisons made outside the 25-to-75-watt range of this paper must be carried out for the actual power range of interest.

For a given type of construction, the power-to-weight ratio of a solar-cell system generally decreases with size; however, the power-to-weight ratio of an isotope system approaches a limit at power levels of approximately 500 watts. In isotope systems, the volume and weight of the isotope should allow for the drop in performance which accompanies a drop in hot- or cold-junction temperatures as the heat output decreases. This effect (for the systems analyzed here) has been eliminated by assuming a heat-dumping device which shunts off the excess heat in decreasing magnitude with time, keeping the heat flow into the thermoelements constant over the system life and permitting optimum system operation throughout its duration. A typical 30-watt radio-isotope thermoelectric generator is shown in Fig. 1.

It is also noteworthy that for long-lived missions (greater than 1 or 2 years) there are three leading contenders for the radioisotope fuel function: Sr^{90} (strontium-90; beta), Pu^{238} (plutonium-238; alpha), and Cm^{244} (curium-244; alpha) having half-lives of 28 years, 86 years, and 18 years, respectively.

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DEVELOPMENT OF SILICON-GERMANIUM THERMOELECTRIC MATERIAL

Until recently it was difficult to seriously compare the thermoelectric generators to the highly reliable solar-cell panels because of the frailty and instability of early thermoelectric materials. It was only since the development of the silicon-germanium (Si-Ge) material by the Materials Section of the RCA Laboratories, Princeton, that valid comparisons could be made. In thermocouple (thermoelectric) systems using the proven Si-Ge couples or the developmental ceramic-type couples there is a greater expectancy of achieving extremely long mean-time-to-failure than in systems using the older telluride couples. In fact, the small amount of data that exists shows that these static elements are extremely reliable. For this reason, the effect of catastrophic failures of individual thermoelements has been neglected in this paper.

There are several additional reasons for the superiority of the Si-Ge material to the telluride materials:

1) The Si-Ge does not sublime in vacuum whereas the tellurides do and require encapsulation.
2) The Si-Ge material has much greater strength than the tellurides and hence can be made in thinner cross-sections, allowing greater voltage buildups for given amounts of material.
3) The Si-Ge is considerably less dense, and therefore generates lower stresses in a given g-loading than do the tellurides.
4) The Si-Ge has a lower coefficient of thermal expansion than the tellurides and therefore develops lower thermal stresses; consequently it does not require the long-travel spring contacts that the tellurides do.
5) The Si-Ge electrical contacting techniques, as developed by RCA Electropic Components and Devices, permit metallurgical bonding throughout—from the hot junction of the couples all the way to the heat rejecting radiators in a single package—which makes for superior reliability and minimizes thermal and electrical impedances.
6) The ruggedness of Si-Ge facilitates the formation of the material into special configurations to obtain very high values of the length-to-area ratio.
7) The Si-Ge has a melting point in the 1,100 to 1,300°C region, depending on alloying, and can therefore tolerate hot-junction temperatures very close to these figures which allows Carnot efficiencies much greater than the tellurides (which may not be operated above 500 to 600°C).
8) Si-Ge is able to exploit the superior Carnot efficiencies doubly well because the figure-of-merit characteristic increases and then remains essentially constant with temperature up to the region of its melting point.
9) Si-Ge permits the use of smaller heat-rejecting radiators because of its high heat-rejection temperature (the area is an inverse fourth-power function of temperature in radiative-heat rejection).
10) Finally, for systems of equal efficiency, the Si-Ge radiator need be only half as large as a telluride radiator. Thereby permitting greater ease of packaging which, on a spacecraft, is often as decisive a factor as system weight.

WEIGHT

Since the artificial introduction of electrons into the natural radiation belts, there has been increasing concern about the usefulness of solar cells because of their sensitivity to radiation damage. (This concern has accelerated interest in power systems using isotopes for which the energy-converter elements are less sensitive to, and/or better shielded from, radiation.)

Because all solar-cell arrays use a transparent cover over the cells (initially used to increase thermal emissivity of the cells), the weight of solar-cell arrays is influenced by the thickness of this cover. To solve radiation-damage problems, the thickness of the covers has been varied as a function of the radiation protection desired and of the allowable weight and area. Where the radiation was very high and available array area limited, thickness of fused silica has been as high as 70 mils. (The RELAY communications satellites developed by AED for NASA have 60-mil covers.) Synthetic sapphire with twice the density, and half the thickness, has also been used instead of silica.

Where solar-cell array weight was the prime consideration and available area was not restricted, cover thickness was selected to yield the optimum weight; this cover thickness is generally in the range of 6 to 30 mils. For many of the comparisons shown here, the orbit causing the greatest radiation damage has

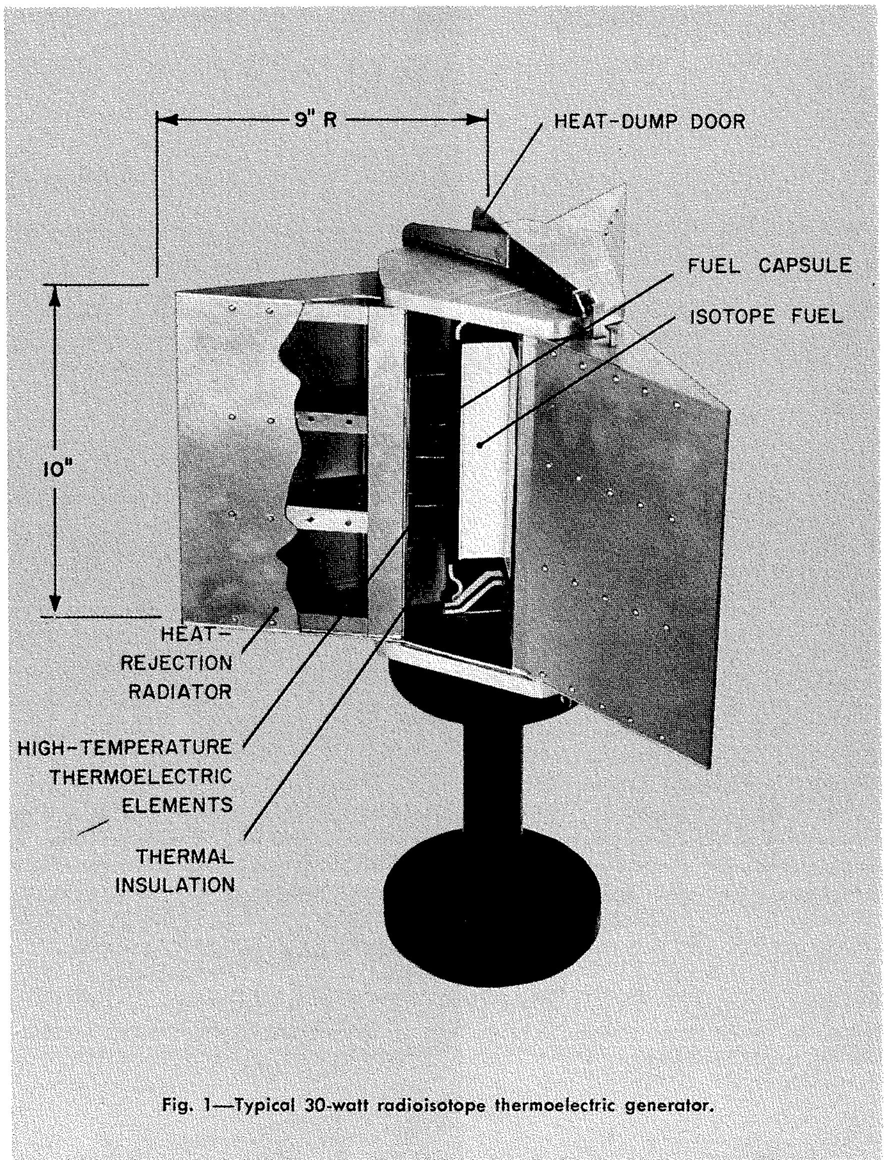


Fig. 1—Typical 30-watt radioisotope thermoelectric generator.

been arbitrarily selected based on radiation-belt data of July 1962 (the highest recorded to date); this is an equatorial orbit having a 2,300-nautical-mile altitude.

The number of electrons and protons encountered, per unit time, in such an orbit is approximately ten times as great as would be encountered in a polar orbit of the same altitude and perhaps 100 times as great as the fluxes encountered in orbits having different altitudes. There are many orbits below 350 miles in which the damaging fluxes to be encountered are almost negligible. However, it should be kept in mind that these fluxes are calculated for the values existing shortly after July 9, 1962, and that they have been steadily decreasing since. It is estimated that these fluxes could be artificially increased by several orders of magnitude; hence choice of the present worst-case orbit may not be conservative with respect to the solar cells if high-altitude nuclear weapons testing were resumed. In Fig. 2, the weight per unit of power is plotted against the percentage of degradation of the solar-cell array. Values for both oriented and unoriented arrays, with both 6-mil and 60-mil covers, are shown.

Time scales indicate the duration of orbital exposure required to produce the degradation shown (for the worst-case orbit). Also shown are the specific weights (pounds-per-watt) for two radioisotope thermoelectric generators (RTG), one using a beta-emitting isotope and the other using an alpha-emitting isotope. Specific weights for an (alpha-emitting) radioisotope thermionic system (RTI) are as good as, or better than, the alpha-emitting RTG for short lives (6 months to a year), but are not plotted because of the early status of their development. From these curves, it may be seen that for missions involving considerable degradation, oriented solar-cell arrays with very thin covers weigh less than most RTG's. However, in certain respects the unoriented arrays are less attractive than RTG's with alpha isotopes; unoriented arrays with the heavier covers (for longer mission life beyond a specific amount of damage) are also less attractive than some RTG's with beta isotopes. It should be borne in mind that the values shown here are for the power output of the solar-cell arrays when illuminated; the influence of the storage systems required to supply power during unilluminated portions of the orbits will be treated in this presentation. However, this storage problem immediately makes the RTG and RTI units more attractive than is apparent from Fig. 2. The weights shown for the solar arrays include the weights of the solar cells, covers, adhesives, and substrate structures; the weights for the RTG and RTI units include minimum equipment shielding and the voltage-conditioning devices required to raise the output voltage to 28 volts.

COSTS

The costs required to obtain a given amount of power cannot be as closely estimated as the weights. Fig. 3 shows several curves of the estimated dollars per watt, again versus the percentage of degradation of the solar-cell array; also shown are the costs for RTG units. These costs are averaged for five-unit total production and include development costs for initially producing the first three or four units; note that the Pu^{238} RTG, which is lighter and less available than the Sr^{90} RTG, is much costlier. Again the oriented solar-cell arrays are attractive up to a considerable percentage of degradation, whereas the unoriented solar-cell arrays soon become less attractive than the Sr^{90} RTG; however, they remain cheaper than the Pu^{238} systems. The costs shown are strictly those for hardware and do not take into account the special efforts required to demonstrate safety of the isotope systems. These costs are very dependent on individual spacecraft requirements and are shown for order-of-magnitude only.

SENSITIVITY TO ENVIRONMENTAL EXPOSURE

Most spacecraft environments include exposure to hard vacuum, micrometeorites, and corpuscular radiation (from natural and artificial radiation belts and from solar events). The problem of vacuum operation has been adequately solved for the solar cells, and vacuum generally produces no measurable degradation. Micrometeorites can produce degradation in solar-cell arrays, but very few spacecraft have been degraded significantly by this means. Solar cell arrays, which generally consist of many thousands of individual cells, can survive considerable numbers of individual cell failures before beginning to show any marked degradation in total output. However, because solar cells must be mounted external to the spacecraft, they are vulnerable to the rarely occurring micrometeorite bursts. (Radiation damage will be discussed later in this section.)

For isotope-powered thermoelectric systems, the hard vacuum can pose problems, since it affects such materials as tellurides (which have high vapor pressures at operational temperatures). Thus, isotope-powered thermoelectric systems may require encapsulation, which involves additional weight. On the other hand, the Si-Ge thermoelectric materials are stable in vacuum over their range of operating temperatures and require no protection. However, in all cases temperature limits are imposed in vacuum operation; these limits are functions of the melting points of the base-material constituents and of the vapor pressures of the metallic bonding materials and must be kept in mind when considering space applications. Exposure to the abrasive types of micrometeorites generally has no effect on thermoelectric systems except that it may modify the absorptivity and emissivity of radiator surfaces. Since these surfaces are often light-colored ceramics, abrasion cannot substantially alter their properties. Another reason that the radiation-damage problem for thermoelectric elements is considerably less for alpha-isotope systems than that for solar-cell systems is that the semiconductor materials in the thermoelements are much less radiation sensitive and a continuous defect-annealing process is taking place at the elevated operating temperatures (200°C to 900°C). This lower sensitivity results from the different doping levels of the elements and because the structure of the thermoelectric generators includes a fairly heavy radiator which shields the elements. Even in beta-isotope RTG's, Bremsstrahlung X-rays produce less than 5% degradation in a 3-year mission when the elements are unshielded.

RELIABILITY

The problem of random failures on solar-cell arrays is treated during design by selecting series and parallel configurations to minimize the effects of individual cell failures. Such series-parallel arrangements are based on the relative probabilities of open-circuit and short-circuit failures. One possible cause of random cell failures is the thermal cycling that takes place as the arrays are passed in and out of the earth's shadow. The over-all effect of random failures generally has not been measurable on satellites that are in orbit. Failures which have occurred in solar-cell power systems have been associated with control and switching circuits and with the storage subsystems.

The reliability of the thermoelectric isotope system should be very high because the thermal elements are not subjected to any extreme thermal cycles but generally operate over fairly constant temperature ranges. However, because there are many fewer elements in an RTG than in a solar-cell system, a single failure can have a greater percentage of influence on over-all RTG performance.

Another reliability problem in an RTG

system is in the heat-dumping device, which may be used to provide the thermal shunt path during the early portions of power system life to maintain a constant heat input to the thermocouples as the isotope decays. There are RTG systems which, because of the long half-life of the isotope, require no heat dumping, or in which the heat-dumping mechanism may fail without catastrophically harming the system.

VOLUME AND AREA

Because of the large area required for an oriented solar-cell array, such arrays occupy considerable space in the launch vehicle. The power density of an oriented array is approximately 0.01 watt/cm.[2] In many vehicles the solar-cell array uses up all of the volume available within the shroud or nose cone of the launch vehicle. However, the RTG, because of its higher power density, is packaged in a much smaller assembly, is easier to position on the spacecraft, and presents fewer problems in integration with the launch vehicle.

GROWTH POTENTIAL

Because in many spacecraft the solar-cell arrays completely fill the available volume, it is often not possible to increase the power level of the spacecraft to keep up with development of the other spacecraft systems. Advanced missions often must be compromised, by changing the duty cycle or the number of equipments, to compensate for the lack of extra power. However, the RTG's which may constitute only a third or quarter of the allotted spacecraft volume, can readily supply two or three times as much power output without unduly affecting the available volume.

RADIATION DAMAGE TO SOLAR CELLS

The primary particles causing radiation damage are the electrons and protons trapped in the earth's magnetic field. Radiation damage also can be produced by the proton flux created by solar flares.

Distribution of Electrons

The original Van Allen belts were described as consisting of two belts, of generally toroidal shape, lying in the plane of the earth's magnetic equator (displaced 11° from the geographical equator). These two belts are centered at 2,000-mile and 10,000-mile altitudes, respectively. The belt presently of major interest is the inner belt, as the electron density of this belt was artificially increased in July, 1962. The present energy distribution in the inner belt is assumed to be that of a fission spectrum in which the average energy of the electrons is somewhat greater than one Mev. The flux measured in late July of 1962 was approximately 10^9 electrons/cm^2/sec at 2,300 nautical miles above the magnetic equator. Fluxes given for other altitudes above 500 miles are as low as 10^5 electrons/cm^2/sec.

Distribution of Protons

The energy distribution of protons in the Van Allen belts is not very well known, but measurements indicate the existence of a spectrum with a proton density which is an inverse logarithmic function of energy level; a significant portion of these protons have energies in excess of 40 Mev. At the heart of the inner belt (again 2,300 nautical miles above the magnetic equator) the flux rate is on the order of 10^6 protons/cm^2/sec. The proton flux produced by solar flares, even at the maximum expected frequency of these flares, is generally considerably lower than the flux within the geomagnetic belts. However, for each space power system the expected solar protons are calculated by using the best available flux levels per event. This data is currently being modified.

Damage Due to Electrons and Protons

Many organizations have conducted experiments to determine the solar-cell damage caused by electrons and protons. As more is learned about the content of radiation belts, the investigators attempt to make their measurements at energy levels which correspond more closely to the expected environment in space. To date, most electron-damage testing has been done using electron energies of about 1 Mev. Since the fission spectrum does include electron energies up to the region of 5 to 6 Mev, further tests are being undertaken at these higher levels. The range of proton energies used in laboratory tests has been predominantly between 17 and 40 Mev. The proton-damage testing is especially difficult because this testing usually requires the use of large particle accelerators, such as synchrotrons, which generally are not available. However, the experiments performed are in reasonably good agreement as to the estimates of solar-cell radiation damage caused by electrons and protons. The solar cells initially produced in this country for spacecraft were of the p-on-n type, in which the sensitive surface is the positive terminal of the solar cell. The more recently developed n-on-p solar cell was proven by RCA to be more radiation resistant than the earlier type and has now been universally accepted as the standard cell for earth-orbiting spacecraft. The damage curves (Figs. 4 and 5) show the differences in dam-

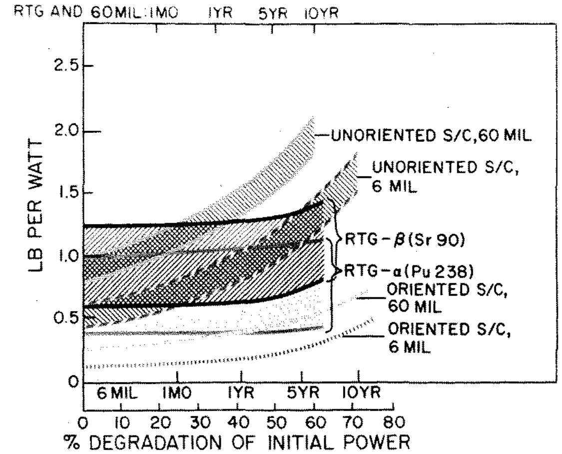


Fig. 2—Comparisons of weight per unit power for nuclear and solar-cell systems.

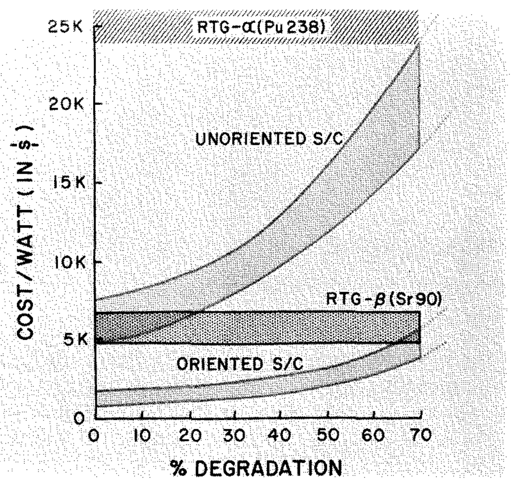


Fig. 3—Comparisons of cost per unit power for nuclear and solar-cell systems.

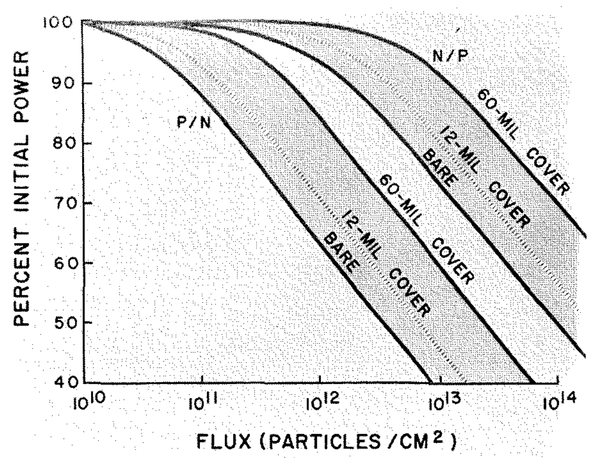


Fig. 4—Effects of electron radiation (integrated flux) on solar cell output power.

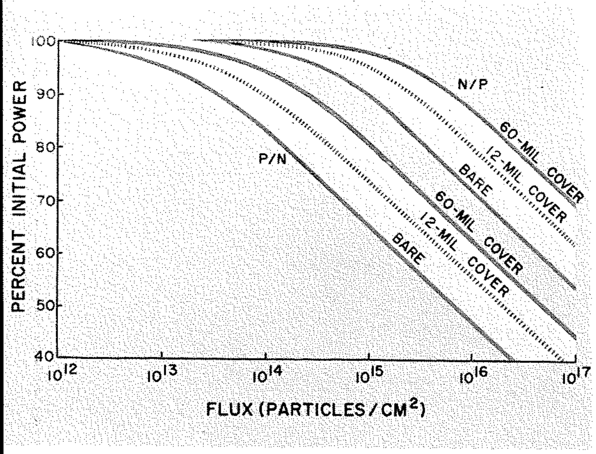


Fig. 5—Effects of proton radiation (integrated flux) on solar cell output power.

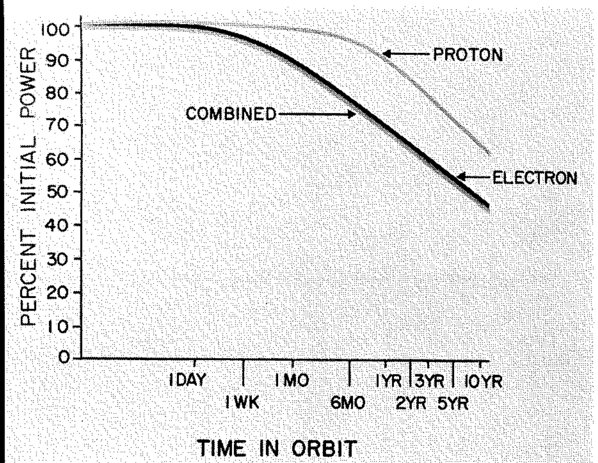


Fig. 6—Percent power degradation versus time in orbit, for n-on-p solar cells.

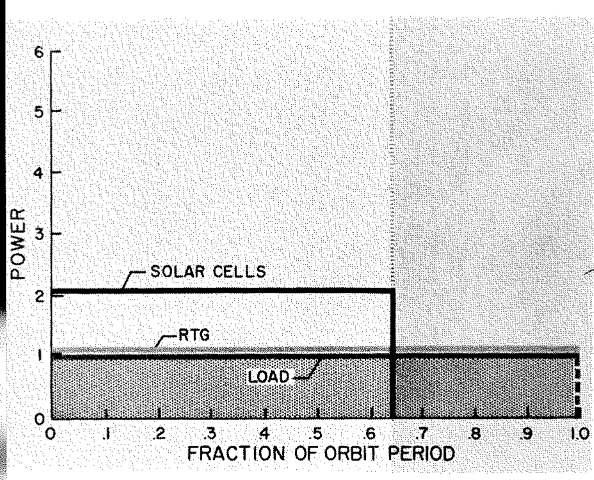


Fig. 7—Steady load power profile.

age rates for the p-on-n and the n-on-p types and also show the effects of varying the thickness of transparent covers; the cover material indicated is fused silica. Synthetic sapphire also may be used as a cover material; its density, which is twice that of the fused silica, permits reduced thickness but cannot influence system weight. Because the sapphire has poor initial transparency, its only virtue is longer system life, as the "browning" caused by radiation is slightly less rapid than that of the fused silica. In Figs. 4 and 5, the percentage of initial solar power is plotted as a function of the integrated flux, with the flux measured in particles per square centimeter unidirectionally impinging on the solar cells. Fig. 6 shows the percentage of initial power plotted as a function of time in orbit, for the 2,300-nautical-mile equatorial orbit. The proton and electron damage rates shown assume the use of 60-mil fused-silica covers. A third curve shows the combined radiation damage effect on the protons and the electrons. The degradations in initial power from the combined curve were used to plot the time points for the 60-mil covers, shown in Fig. 2; a similar combined damage rate was calculated for 6-mil covers and was plotted as the 6-mil line in Fig. 2. The damage rates shown here are for silicon solar cells; a newer type of solar cell is constructed of gallium arsenide material. At the 25% degradation point, which is the common measure for solar cells, these new cells have ten times the life of the n-on-p silicon cells. These gallium arsenide cells are under active development at RCA Somerville.

Several solar-cell power systems on spacecraft in orbit have had accurate telemetry systems which enable the radiation damage rates to be recorded on earth. These experiments have shown that the laboratory data can be used to predict the time required to achieve a given degradation to within a factor of three. It should be noted again that the degradation rates shown in Fig. 6 are for the worst-case orbit, and that many orbits used in systems under consideration have radiation rates one or two orders of magnitude less severe than those assumed.

INFLUENCE OF POWER PROFILE ON SYSTEM SELECTION

The following paragraphs discuss power profiles typical of various spacecraft systems and the ways in which these profiles can influence the desirability of different power systems. The first type of power profile to be studied is one which requires a steady power at all times and has no peak loads. Fig. 7 shows such a profile for an orbit which places the satellite in the sun for 65% of each orbital period.

Power level is plotted as a function of time and it is obvious that an RTG with its associated power conversion electronics need be large enough only to match the load requirement, whereas the solar-cell array must have a power output which is considerably higher than the load need. The extra power from the solar cells is required to charge a storage device during the sunlit period, thus providing the energy required during the 35% of the orbit when the vehicle is in darkness. This energy which the solar cells must provide in excess of the load must account not only for the dark-time energy but also for the low efficiency of the storage device, which may be in the order of 60%. Another typical power profile is shown in Fig. 8. In this profile there is a peak load which is six times as great as the steady load; the peak load is assumed to continue for 20% of the orbit. If it is assumed desirable to design the smallest possible RTG or solar-cell array, either system will require an energy storage device. The battery in an RTG system is required to store only enough energy in excess of the steady load requirements to supply the difference between the RTG output and the peak power requirements. Of course this RTG output must also take into account the efficiency of the storage device which provides the peak. Again the solar-cell array power output must be greater than that of the RTG because it must provide not only the difference between the solar-cell array output and the peak power but also the energy required during the dark period. For these two types of power profiles the weight per unit power of steady load has been calculated for various power systems. Figs. 9 and 10 plot specific weight (pounds per watt) versus time for oriented solar-cell arrays with batteries, unoriented solar-cell arrays with batteries, and two RTG systems with batteries. Fig. 9 shows the specific weight versus time (years) for the power profile shown in Fig. 7 (the steady load). For this steady-load profile, the oriented solar-cell array is only slightly better than the 1965 (advanced) RTG with alpha emitter; and both the 1963 and 1965 RTG's are superior to the unoriented solar-cell array. It should be observed that the decay of the isotope is not included in the RTG system weights; in a three-year period this would increase system weight by 3 to 5% for Sr^{90} (1963) but would be negligible for Pu^{238} (1965).

Again, it should be noted that in each of these four cases the weight of the required storage battery has been included. In Fig. 10, plotted for the peak-load situation, the oriented solar cells again are slightly lighter than the alpha-emitting RTG but the unoriented solar cells and the RTG with beta emitter are almost equivalent. A majority of the spacecraft in orbit or being designed use unoriented solar-cell arrays for steady load profiles or profiles in which the peak-to-average energy and power ratios are not very great. The RTG as presently being designed is very competitive with the unoriented solar-cell arrays; as the ratio of peak-to-average or peak-to-steady-load increases the RTG becomes relatively less attractive but still remains a strong competitor, as shown in Fig. 10. With the advent of the alpha-emitting isotopes in reasonable quantities the RTG should have no difficulty in competing with the unoriented solar-cell arrays and should begin to come into contention with the oriented arrays. It must be noted, however, that oriented solar cell arrays require pointing accuracies of ± 10° to the sun-earth vector. The reliability, complexity, cost, weight, and dynamics problems associated with such orientation systems often override array weight and size advantages they provide. The outstanding justification for sun-oriented arrays exists on vehicles such as solar probes in which orientation must be provided for the experiments regardless of power system needs. Note also that an increase in the radiation damage effects will make the solar-cell curves of Figs. 9 and 10 steeper with time and will increase the range of cases in which the RTG's are distinctly superior.

DIFFICULTIES WITH ISOTOPE POWER SYSTEMS

In comparing the uses of solar-cell and isotope power systems, the spacecraft contractor faces the problem of incorporating the isotope power system into the design and into the qualification-test procedures. The requirements for safety demonstration, and the stipulation that all components of the spacecraft be environmentally tested with no modification and with no subsequent assembly or disassembly allowed, lead to conflicts which are not as yet wholly resolved. In contradiction to the test requirements, it appears desirable, when using such beta-emitting isotopes as Sr^{90}, to provide synthetic electrical-heat sources or alpha-emitters for all testing of the RTG up until the time of launch, and to insert the beta-isotope capsules only on the launch pad (using a well-shielded remote handling fixture). Another problem faced by a systems contractor is that highly specialized and expensive facilities are required for handling the isotopes, for safety test demonstrations, and for conducting all qualification and environmental tests. The special requirements for hazard prevention generally will increase the development time of nuclear power systems.

The present schedules of isotope availability seem to indicate that there will be problems in obtaining the required quantities when several spacecraft systems require the same isotope simultaneously. The fission products (mostly beta-emitters) are much more available and economical than the alpha-emitters which must be bred in reactors with three-year lead-times and at considerable cost. Still, before isotope systems can come into general use, the spacecraft systems industry must be assured that lack of availability will not preclude use of a selected isotope system.

It is hoped that the entire question of safety and management of isotope material can be standardized among the government spacecraft agencies, the Atomic Energy Commission, and the spacecraft industry. One of the technical problems to be resolved is compatibility between the need for isotope materials that melt at higher temperatures and the requirement that the isotope "burn up" into sub-micron-sized particles on re-entry into the atmosphere. (The higher melting temperatures are required to permit increased junction temperatures for higher efficiencies in the electrical conversion devices.)

CONCLUSIONS

The development of RTG's vital because: 1) The flux encountered in the radiation belts can increase; 2) The requirements for storage batteries impose a severe reliability limit on spacecraft which need them; and 3) The growth limit on solar-cell arrays has been approached for several of the available launch vehicles in the power ranges projected for the near future.

Radioisotope-fueled power systems are of extreme interest now that high-temperature thermoelectric and thermionic conversion units are being produced that can achieve system efficiencies high enough to make the isotope systems attractive. The potentially higher reliability available with static conversion devices, especially where the systems do not require chemical storage, opens up an entirely new range of system lifetimes. This increased reliability can reduce the cost of long-term operational satellite systems per unit energy and make these systems very attractive. Indeed, such power subsystems may become the most reliable devices on future spacecraft.

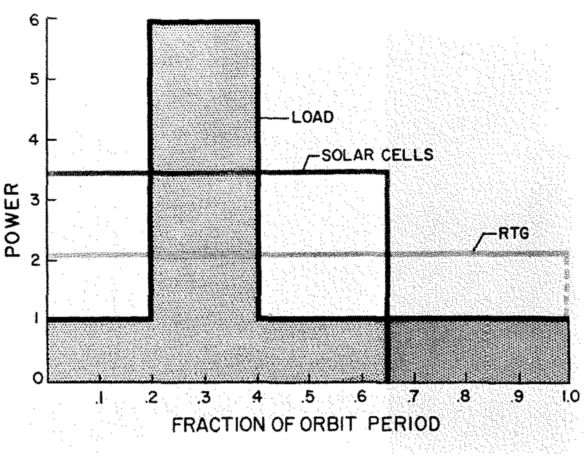


Fig. 8—Peak load power profile.

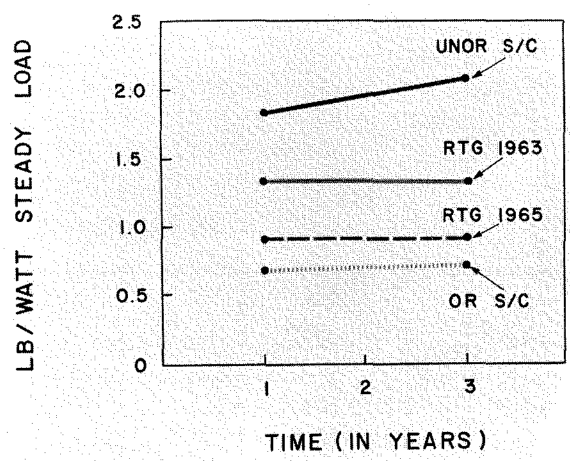


Fig. 9—Weight/power requirements for steady load power profile.

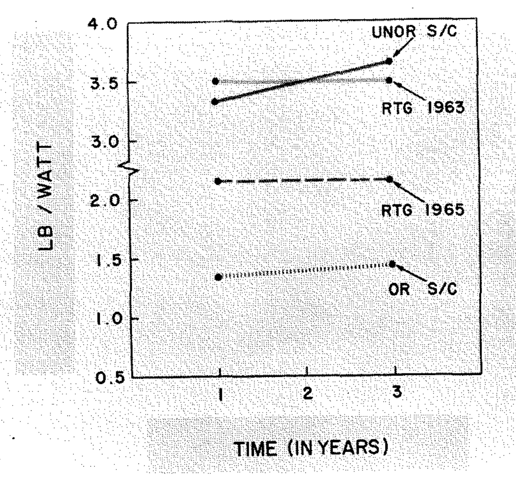
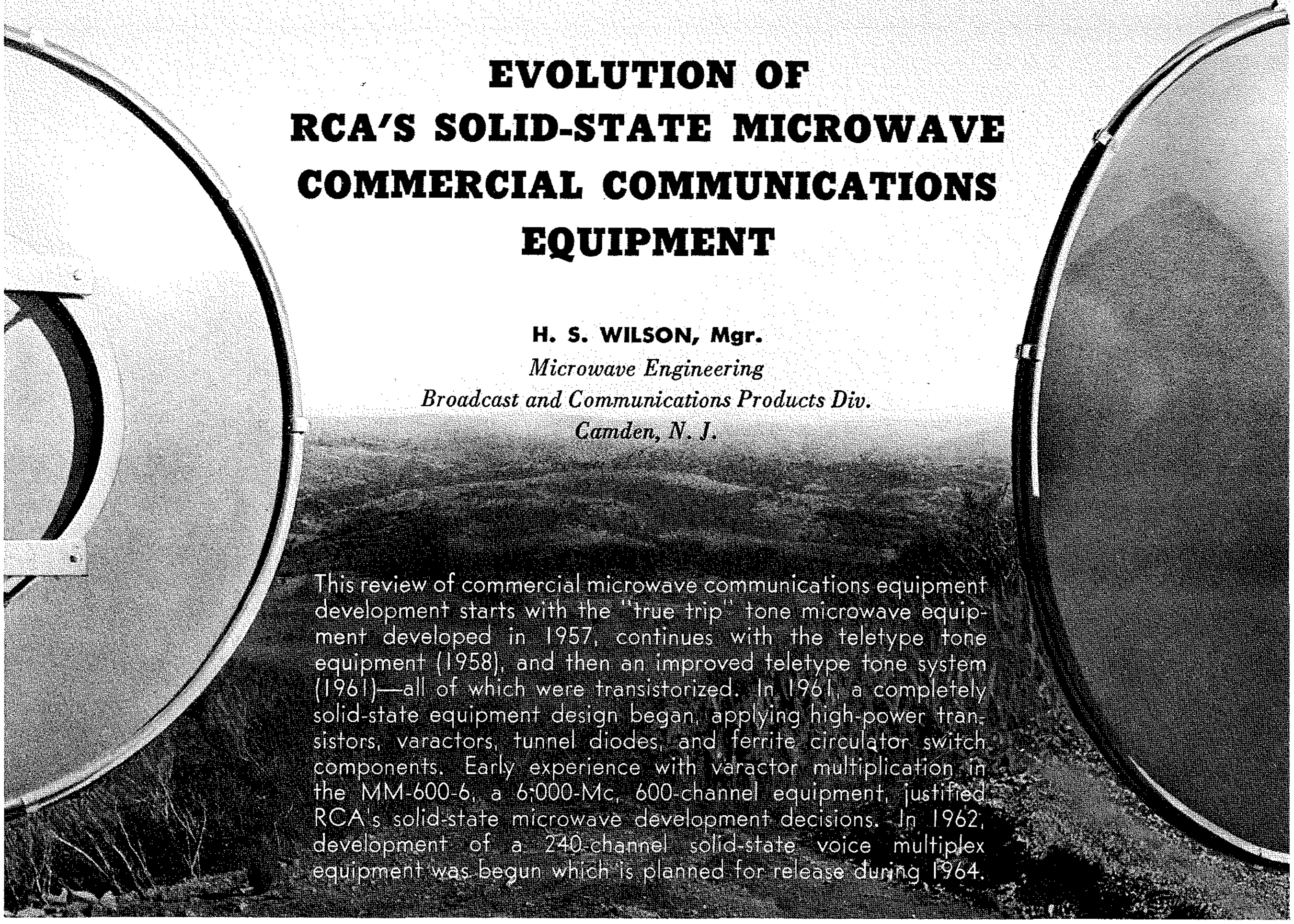


Fig. 10—Weight/power requirements for peak load power profile.



EVOLUTION OF RCA'S SOLID-STATE MICROWAVE COMMERCIAL COMMUNICATIONS EQUIPMENT

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This review of commercial microwave communications equipment development starts with the "true trip" tone microwave equipment developed in 1957, continues with the teletype tone equipment (1958), and then an improved teletype tone system (1961)—all of which were transistorized. In 1961, a completely solid-state equipment design began, applying high-power transistors, varactors, tunnel diodes, and ferrite circulator switch components. Early experience with varactor multiplication in the MM-600-6, a 6,000-Mc, 600-channel equipment, justified RCA's solid-state microwave development decisions. In 1962, development of a 240-channel solid-state voice multiplex equipment was begun which is planned for release during 1964.

For many years, RCA has been designing and producing commercial communication equipment, radio relay equipment, and designing microwave communication systems — for general communications, public utility, state authorities, and private industry.

A variety of communication services are performed through the use of microwave relay systems. Microwave equipment provides an efficient means for the user to more effectively fulfill his customer service responsibilities. To perform such services, line-of-sight microwave equipment offers the cheapest and most reliable overland communication system for telephone, telegraph, television and data. RCA has, over the years, produced microwave and voice multiplex equipment to satisfy the market requirements. With the advent of transistors, RCA began an orderly transition in 1957 from tube devices to transistors and other solid-state techniques as they became available. The inherent advantages of such equipment are longer life, less maintenance, lower power consumption and less space than that of its vacuum tube equivalent.

EARLY MICROWAVE DESIGNS

A 2,000-Mc equipment, designated CW-20, was developed in the late forties for use as a point-to-point heterodyne communications equipment to provide service for 24-channel operation; later, this tube equipment was improved to 120-channel performance. A video-relay, broadcast-link equipment using a klystron at 7,000 Mc was also developed in the late forties. Along with such tube type equipments, the Microwave Department developed a 24-channel, voice-multiplex equipment designated MV-124. All of these equipments have had wide usage since their inception.

ENTRY OF THE TRANSISTOR: "TRUE TRIP"

During the 1950's, the Microwave Department took an increasing interest in the possibilities of transistors as devices to replace tubes in communications equipment. In 1957 an opportunity to develop a truly reliable system emerged in the power industry. For many years, protective relaying had been used in electric power transmission systems; one means of primary line protection called *transferred tripping* had really received very little acceptance. In many cases, the carrier equipment and transmission media were inadequate because of the great reliability required. The development of a transistorized high-speed tone equipment providing great reliability without fear of false operation opened this field of endeavor to RCA.

RCA developed a high-speed, completely transistorized tone equipment system called *True Trip;* it transmits and receives relay-trip information within 8 to 12 msec. The complete transistorization of the RCA equipment, plus the use of guard signals set a new standard in the industry for performance of relay tone circuits. The development of the True Trip equipment signified an important forward step toward the ultimate transistorization of communication devices of all kinds (Fig. 1).

Because of the early design limitations of the transistor devices themselves, it was necessary to consider implementing products from low frequencies to high frequencies; therefore, it was natural to consider transistorizing tone, voice, and data equipments long before the transistorization of the point-to-point equipment itself. The Microwave Department decided to stay close to the development and progress of state-of-the-art solid-state devices. As such devices became available, the product line was developed to fill the needs of the markets being served as well as to develop units for use in new markets.

TRANSISTORIZED TONE MULTIPLEX EQUIPMENT

Accordingly, we launched a modest design program in 1958 leading to the development of an 8-channel FSK (frequency-shift-keying) 100-wpm teletype

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multiplex equipment. By 1959, two terminals of this fully transistorized equipment were delivered to Aeronautical Radio Inc. in Hawaii for communications service. Although these equipments were custom built for the application, the basic design objectives were realized; since turn-up, these equipments have operated successfully on a 24-hour/day continuous basis.

AN EARLY ENTRY OF TRUE SOLID-STATE EQUIPMENT

The demand for the use of tone equipment data in industrial communication systems continued. Such tone equipments were needed for use in process control, supervisory control, telemetry, telegraph, data over wire, cable and radio circuits; the tone equipments used either AM or FSK audio-frequency tones. With the experience gained previously, the time arrived in 1959 when a tone product could be developed using low-cost, high-reliability transistors and diodes; these devices would provide a true solid-state equipment with all its advantages of small size, low power consumption, reduced maintenance and increased reliability. Thus, the CT-42 tone equipment was designed (Fig. 2).

The CT-42 is an FSK audio-tone equipment. It consists of 24 tone channels in the voice band of 300 to 3,300 cps and of 18 tone channels in the frequency space band of 4,000 to 8,000 cps. For the means of modulation, FSK was chosen to obtain the known advantages of FM performance; this development provided a compact tone equipment that could be placed in a smaller floor area. Continued research by RCA in the areas of low-cost all-purpose transistors, printed-circuits, and modern network synthesis resulted in a CT-42 equipment designed to substantially higher performance standards.

HADDON S. WILSON received a BSC in Electrical Engineering from Queens University, Kingston, Ontario in 1950. He joined the Canadian General Electric Co. test course and in 1951 transferred to the G.E. Microwave Group as a Systems Engineer. After joining RCA's Microwave Department in 1953, Mr. Wilson was engaged as an engineer in multi-channel VHF and microwave systems design and in 1958 became a Group Leader responsible for Systems Engineering for Industrial Communication Systems as well as proposal work for new business. In 1959 Mr. Wilson was named Manager, Microwave Project Operations where he was responsible for the Contract Administration, Financial Control, Production Control and Installation of projects sold by the Microwave Department. In 1962 he became Manager of Microwave Engineering. He is a member of IEEE and is a registered Professional Engineer in the Province of Ontario.

MM-600 MICROWAVE USES SOLID-STATE DEVICES

Another significant development occurred in 1959 when Western Union, who had been seeking communication equipment with a 600-voice-channel capacity to carry messages across the continent, contracted with RCA for the large production of such a microwave equipment—designated MM-600. At that time, RCA engineers had completed the basic design for such an equipment at 2,000 Mc and therefore were excellently prepared to design and produce the 6,000-Mc version system (Fig. 3).

The development of this high-quality microwave equipment permitted a further look into the opportunity of introducing advanced solid-state devices and techniques. Although the transistors then available did not appear capable of the performance necessary, it was believed that the varactors becoming available at the time could be utilized to replace tube-multiplier circuits. Thus, all low-level multiplier stages of the MM-600-6 microwave equipment were developed to use varactor diodes. Throughout the design effort, a careful study of vacuum and solid-state devices assured an optimum selection of components for each application; for example, varactor diodes were used as frequency multipliers, and vacuum tubes as amplifier stages. During the development phase of this MM-600-6 design program, the alarm system was completely transistorized. Transistors and solid-state devices were used extensively in all power supplies and regulating circuitry. The experience with a very-high-performance, fault-reporting system became the basis for future designs of simplified fault and service channel equipment.

Fig. 1—The two equipment racks on the right contain the "true-trip" tone units.

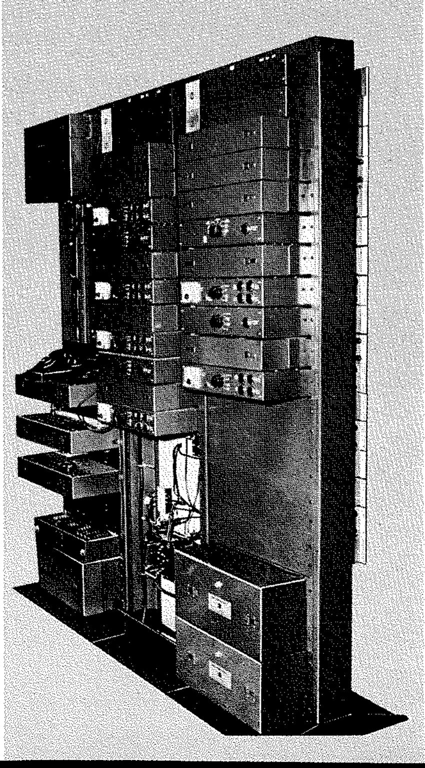
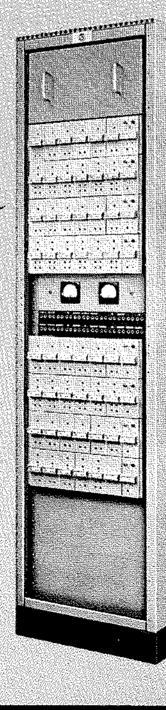


Fig. 2—The CT-42 transistorized tone equipment; inset section shows possible access to receiver module while equipment is in operation.



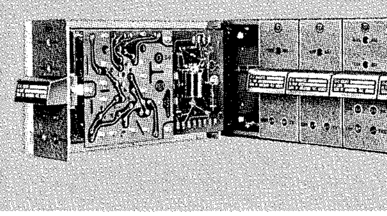
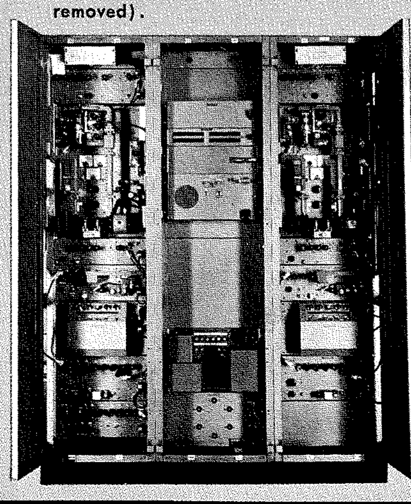


Fig. 3—MM-6006, 6,000-Mc microwave radio relay equipment (doors removed).



CONSIDERATION OF NEW SOLID-STATE MICROWAVE PRODUCTS

With the transistor experience gained in designing tone equipment, consideration was directed toward a new microwave product for the market. Although point-to-point microwave had been available since 1948, it was not until the late fifties that radical changes in the basic design concepts could be considered. So, RCA and other companies began moving toward more extensive use of solid-state devices in their products.

In 1961, other companies were also designing or producing partially transistorized microwave equipment. Most microwave equipments of the 300-channel capacity and below employ klystrons as the transmitting power generators and frequency modulators. When using a klystron in this way, the incoming FM signal is demodulated at a repeater and then remodulated at the next transmitter; such a repeater is called a *remodulation repeater*.

The Microwave Department, in considering the development of an equipment to compete in the 6,000-Mc band, decided to leap-frog the state-of-the-art in the microwave field and design a *completely new, completely solid-state* communications equipment. This equipment would therefore have no thermionic devices of any kind.

The replacement of the transmitter by a solid-state counterpart represents the ultimate so far as the new generation of microwave equipment is concerned, since it eliminates the hybrid approach necessary with equipments requiring high-voltage DC and low-voltage AC power supplies, as well as the low-voltage DC supply required for transistorized circuitry. This approach in the design permitted the equipment to be operated completely from a 48-volt battery with no high voltages being necessary. The challenge to the designers was considerable, since the work involved application of state-of-the-art high-power high-frequency transistors, high-frequency varactors for multiplier circuits, and a low-noise tunnel diode amplifier for use as input to the 6,000-Mc receivers. Many problems involved the development of high-quality, low-VSWR circulators and ferrite switches to complement and complete the equipment.

THE CW-60 SOLID-STATE MICROWAVE

The final solid-state microwave equipment design, known as CW-60 (Fig. 4), serves a radio-frequency band (5,925 to 6,425 Mc) and the adjacent operational band (6,575 to 6,875 Mc). The CW-60 utilizes the heterodyne repeater principle long ago determined by communications carriers as the only practical approach to multihop systems employing a large number of channels. High-power high-frequency transistors are used to amplify 120-Mc signals to 8 watts; cascaded tuned cavities employing varactor diodes multiply the signal to 6,000 Mc. The extremely rugged varactor has provided excellent reliability in the MM-600, 6-Gc equipment over the past few years. In the design of the varactor multiplying cavities for CW-60, many hundreds of engineering hours were devoted to attaining stability and easy tunability in the cavity stacks. Since this equipment must be maintained in the field with a reasonably small amount of test equipment, very stable multipliers, easily tunable with normal test equipment, were developed.

The MM-1200

While the 300-channel medium capacity CW-60 was in design, a program was started in 1963 for a 1,200-channel partially solid-state equipment in the 6,000-Mc band. This logical development of a high-capacity long-haul equipment is being carried out at RCA Victor Ltd. in Montreal; the equipment, known as MM-1200, is solid-state design throughout except for a travelling-wave-tube output amplifier. The completion of this design will complement the RCA microwave communications products.

The MM-60

Another development by RCA Victor Ltd. begun in 1963 is a 2,000-Mc low-capacity solid-state remodulation equipment called MM-60. It is a 60-channel equipment designed for excellent performance at low cost and low power drain.

DEMAND FOR GREATER VOICE-CHANNEL CAPACITY

While microwave products were being developed on a broad base to cover several market requirements, it was necessary to give serious consideration to the possibility of expanding our voice-channel capabilities into new areas. A

Fig. 4—CW-60, 300-voice-channel, 6,000-Mc radio relay solid-state equipment.

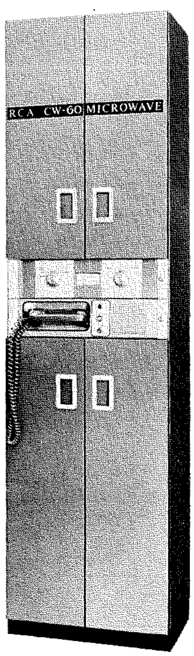
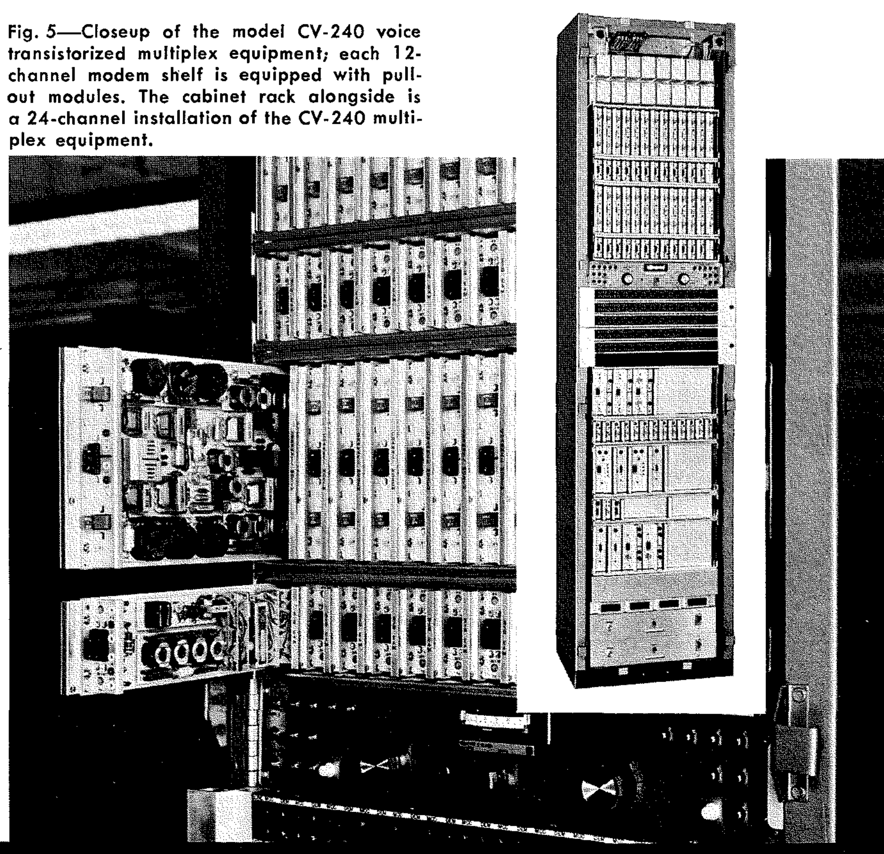


Fig. 5—Closeup of the model CV-240 voice transistorized multiplex equipment; each 12-channel modem shelf is equipped with pull-out modules. The cabinet rack alongside is a 24-channel installation of the CV-240 multiplex equipment.



significant segment of our market had begun to require voice-channel capacity greater than that of the RCA equipment then available. High-capacity multiplex equipment had frequently been considered as a possible product line within RCA; however, it had not been possible to begin this type of program prior to 1961. The tube-type 24-channel MV-124 had been our only product entry in this high-capacity voice channel area. The market expansion over the years dictated that RCA consider the development of a higher-capacity voice multiplex.

While the radio-frequency programs were underway in 1961, an extensive study was begun of voice multiplex design. A system review in early 1962 resulted in the design of 240-channel voice multiplex equipment to be completely transistorized—meeting all the CCITT International toll quality performance plus compatibility with AT&T standards. It was also decided that the equipment should be capable of ultimate expansion to 600 channels.

THE CV-240 ALL-SOLID-STATE MULTIPLEX

The final new equipment design, called CV-240 (Fig. 5), was developed on the basis of six important design features:

1) All solid state.
2) CCITT performance and compatible with Bell system.
3) Universal channel modem.
4) High packaging density.
5) Low power consumption.
6) Low per-channel cost.

From the start of this program, it was recognized that development of an RCA multiplex product line involving a large variety of complex filters and equalizing networks necessitated a network design capability beyond the resources and potential then available to this Engineering Department. To solve this, a powerful network design capability has been developed; this includes a potential analog field-plotting table used to obtain transfer functions, and new computer programs for synthesizing, analyzing and realizing network functions. During the development, it has been possible to create low-cost bandpass and lowpass filters which can be easily tuned; these filters are the heart of the channel unit.

The multiplex equipment, CV-240, must operate on a continuous 24-hour basis with a minimum of care and maintenance. Therefore, all equipment is designed with the highest quality and reliability to meet international standards under the most difficult environmental conditions. Packaging includes plug-in units which can be replaced with ease. System and equipment philosophy is based throughout on the need for communication systems to grow and change with the expansion and change in traffic demands. The CV-240 solid-state microwave will provide a versatile equipment available for sale in the United States and International markets; the CV-240 equipment is planned for release during 1964.

WHAT OF THE FUTURE?

The plan to develop a diversified solid-state product line has to a large extent been accomplished; but, it is necessary to continue this development to fulfill future marketing requirements in other areas. Emphasis continues on the design of a broadly based product line suitable for many types of customer applications in industrial and other markets, both domestic and international. Thus, future work in 1964 and beyond is an important part of the Microwave Engineering Department's plans. Among the programs now underway to further expand the solid-state produce line are three important additions started in 1964, as follows.

The TVM-60

RCA pioneered video-relay microwave at 7,000 Mc many years ago, and this continues to be a popular item with broadcasters. However, in the past few years, the need has arisen for a new and modernized line of equipment to replace the microwave tube video-relay called TVM-1. With the success in developing a microwave solid-state industrial equipment, the decision was reached that modern solid-state equipment could be used to fulfill portable requirements for TV broadcasters. With this in mind, a new design program was begun to develop such broadcast equipment (designated TVM-60, Fig. 6). The development of the portable equipment will include the necessary sound diplexing and portable packaging for the video relay market.

CW-60 to be Extended to Higher Frequency

The second addition will be an extension of the 300-channel CW-60 microwave equipment to a higher frequency; at present, it is operated in the 5,925-to-6,425-Mc and 6,575-to-6,875-Mc microwave bands. It is now intended that the same commercial product design be extended so that it will operate in the band of 7,125 to 8,400 Mc.

CV-240 to be Extended to 600-Channel Capacity

The transistorized voice channel equipment, CV-240, must be extended to 600-channel capacity in order to meet the requirements of large long-haul systems. A 600-channel multiplex will be needed particularly in the international markets. To meet these needs, work on extending CV-240 to 600 channel capacity has been started.

CONCLUSION

With solid-state commercial microwave communication equipment operating in the 2,000-Mc industrial band and in the spectrum from 5,925 to 8,400 Mc, RCA will be in an excellent position to cover almost all point-to-point and portable communication requirements in its various markets. Moreover, the availability of a solid-state voice-multiplex equipment with high capacity and high performance, as well as the solid-state CT-42 tone line, completes a transition from the use of vacuum tubes to complete application of solid-state devices in our equipment line.

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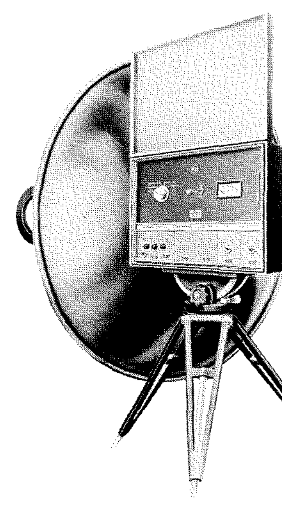
Fig. 6—Model TVM-60 portable 6,000-Mc video relay equipment.



LAP-DISSOLVE AMPLIFIER FOR TV BROADCASTING

A common TV broadcasting technique is the act of smoothly changing from one picture to another—called "dissolving." The unit described herein allows near perfect dissolves at all speeds, and solves many of the difficulties inherent in previously used techniques. The unit is self-contained, with its own power supply, and can be installed in existing TV broadcast switching systems.

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SINCE the beginning of television, various devices have been developed to provide a means of dissolving from one picture to another. A simple device uses two pots, mechanically ganged. The outputs of the pots are fed to isolation and mixing stages. A picture signal is fed to each pot, and as the common shaft is rotated, the output dissolves from one picture to the other. A servo system is usually used to control the shaft rotation. Two of the main problems encountered with this system are: 1) it is difficult to make the two pots track so that the decrease in amplitude of one picture equals the increase in amplitude of the other; and 2) the pots tend to get noisy and cause picture break-up as a dissolve is made.

Another approach uses balanced amplifiers and a remote-controlled bias system which causes the gain of one stage to decrease as another increases. Such a unit usually has tracking and balance adjustments which are difficult to adjust and keep adjusted. When a fast dissolve is made, severe bounces and level changes are observed in the output signal.

The lap dissolve amplifier described herein uses emitter followers to provide input isolation. Control is accomplished by the use of light dependent resistive (LDR) elements so that the signal circuit is completely isolated from the control circuit. The abovementioned problems are nonexistent, and a near perfect dissolve, at all speeds, can be made. This unit is self-contained, with its own power supply, and can be installed in existing switching systems by simplifying the control system.

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THEORY OF OPERATION

Some of the important considerations for a lap dissolve amplifier are:

1) Input isolation must be provided to prevent crosstalk.
2) The impedence of the signal path must be kept low at all times so that the frequency response remains constant during the dissolve.
3) There must be no DC change during the dissolve so that the output signal does not bounce with a fast dissolve.
4) The signal path must be isolated from the control circuit so that noise and crosstalk will not be introduced from the control circuit.
5) The control circuit must have positive control at all times to prevent lagging and hunting during a slow dissolve.
6) The control circuit must act in such a way, that the decrease in amplitude of one signal equals the increase in amplitude of the other, so that no amplitude changes are observed in the output.
7) The controlled circuit must be capable of turning one signal off completely when the other signal is on completely.

Emitter follower stages are used for both inputs of this unit to provide input isolation and a low impedance signal source. The LDR elements are used in series with the signal paths, from each emitter follower, to control the amplitude of each signal. The signal outputs of the LDR elements are combined and fed to a line amplifier. The LDR elements are controlled in such a way that as the resistance of one increases, the resistance of the other decreases. The relative amplitude of the two signals, fed to the line amplifier, depends on the ratio of the resistances of the LDR elements. Therefore, the decrease in amplitude of one signal equals the increase in amplitude of the other.

The LDR elements used in this unit are Raytheon Raysistors. The Raysistor is a four terminal electro-optical device consisting of a light source and a photocell assembly in a light-tight case. A variation in the voltage to the light source causes a change in the photocell resistance. No electrical connection exists between the control (light source) and signal (photocell) circuits. The Raysistor was selected because of convenient packaging and resistance ranges available. The CK 1104 Raysistor has an *on*-resistance of about 50 ohms and an *off*-resistance of about 1 to 10 megohms. The *on*-to-*off* resistance ratio allows complete control so that one signal can be full *on* when the other signal is full *off*.

CIRCUIT DESCRIPTION

Referring to Fig. 1, the *A* and *B* signal inputs are fed to emitter followers *1* and *2*, respectively. The CK 1104 Raysistors determine the amplitude of the signals, from emitter followers *1* and *2*, which are fed to emitter follower *3*. The Raysistor light sources are connected in series from 24 volts to ground and are remotely controlled by a single 2,500-ohm pot. When the swinger of the remote control is at ground, the left-hand light source has full voltage across it, and the right-hand light source is shorted. This allows 100% *A* signal and 0% *B* signal to be fed to emitter follower 3.

The opposite is true when the swinger of the remote control is at 24 volts. Equal voltage is applied to the light sources when the swinger is at electrical center. With this condition, equal 50% *A* and *B* signals are fed to emitter follower *3*. As can be seen, a smooth dissolve can be made by moving the remote control from one extreme to the other. The 100-ohm resistor, in series with the control lead to the light sources, limits the maximum voltage applied to the light sources to approximately 22 volts. This extends the lamp source life expectancy to three years plus. At the extreme position of the remote control, the resistance of the signal path of one Raysistor is approximately 70 ohms, while the other is approximately 1 megohm. At the midposition of the remote control, the resistance of each Raysistor is approximately 120 ohms. Because of this, the signal path from emitter followers *1* and *2* through the Raysistor circuit to emitter follower *3* is kept low, and good frequency response is maintained during a dissolve.

A DC balance control is provided so that the DC voltage at the two emitters, of emitter follower *1* and *2*, can be adjusted to be the same with respect to each other. This allows a fast dissolve to be made without introducing a bounce in the output signal. The response of the Raysistor to a change in control voltage is practically instantaneous, so that fast dissolves are possible.

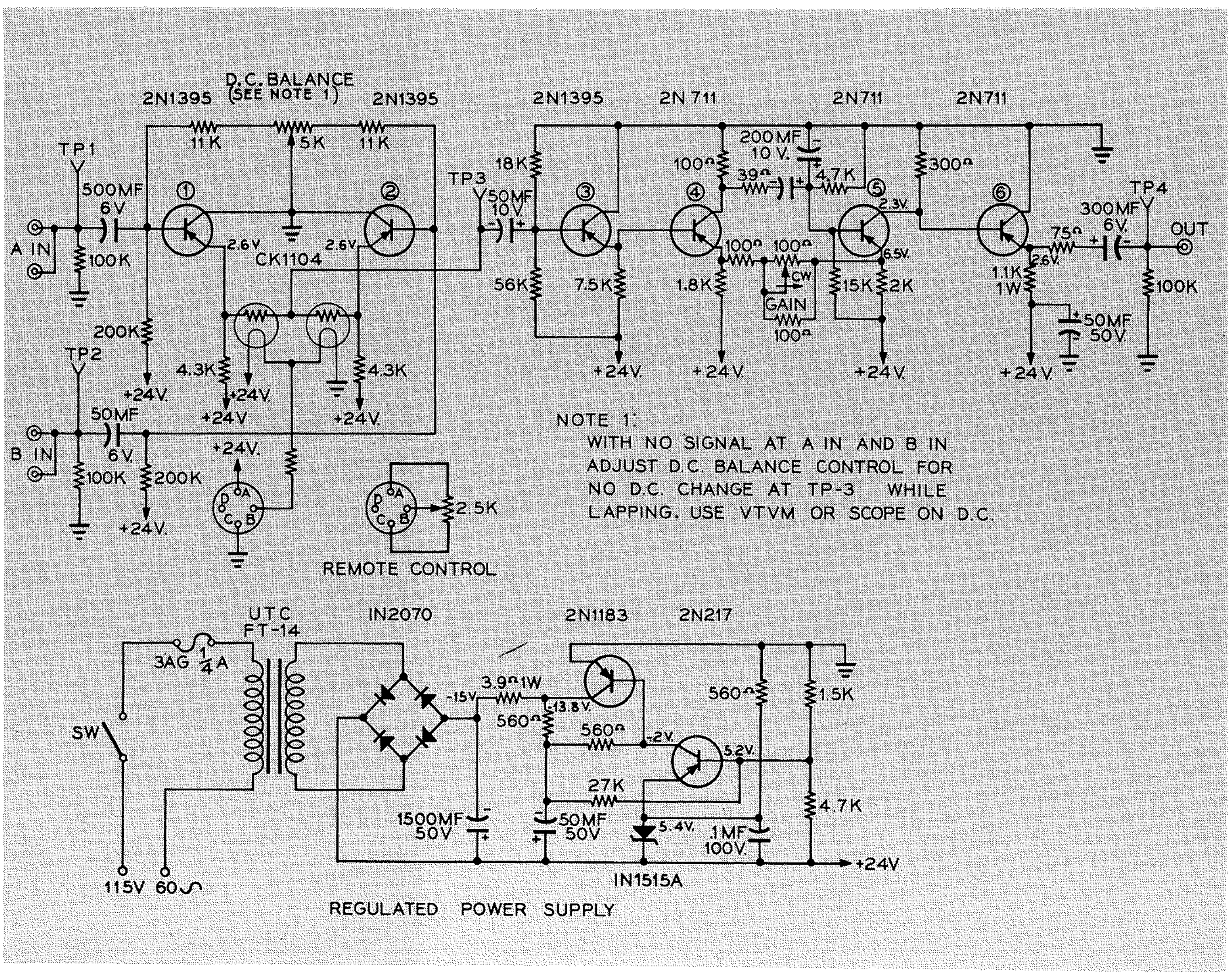
Emitter follower *3* presents a high input impedance into which the Raysistors may work so that no level or frequency response change will occur during a dissolve. The signal from emitter follower *3* is fed to inverter *4* which drives the common base circuit *5*. The amount of drive to the common base circuit *5* is controlled by the gain control. Emitter follower *6* provides a 75-ohm line feed. The network between the collector of inverter *4* and base of common base circuit *5* provides low frequency compensation. The overall gain of the unit is unity, with gain adjustment of ±15%.

INSTALLATION

The lap dissolve amplifier has its own power supply and requires only 115-volt, 60-cycle power. The input impedance is approximately 10,000 ohms and will bridge a 75-ohm feed. The output impedance is 75 ohms, and the gain is unity when feeding a 75-ohm termination. The remote control should be a linear 2,500-ohm pot.

KENNETH W. JORGENSEN completed courses in electronic design engineering at DeForest Training Incorporated (Chicago), an Atomic Energy course at Wright Jr. College (Chicago), and attended UCLA for Advance Color Instruction. Joined the National Broadcasting Company (Chicago) in 1948, as a Television Transmitter Engineer. He participated in the construction of NBC's first TV transmitter in Chicago. In 1951 he was one of the first engineers concerned in the design, construction, and checkout of NBC's Burbank, Calif. facilities. One of his first patent disclosures in connection with color equipment, concerned an automatic carrier balance system. He developed an electronic process to analyze electrophoretic patterns used for diagnostic purposes. He designed an automatic pedestal brightness control device for television cameras which is nationally used by NBC. Among his recent developments is a title insertion unit for television stations and a relay-operated audio fader system currently used at NBC-Burbank.

Fig. 1—Lap dissolve amplifier.



MOBILE COMMUNICATIONS REPEATER REQUIREMENTS

Mobile communications has become a major industry during the past 30 years. Almost every branch of commercial, industrial or professional business uses some form of mobile communications. Extending the area of communications by a properly designed and adjusted "mobile repeater" is covered in this article.

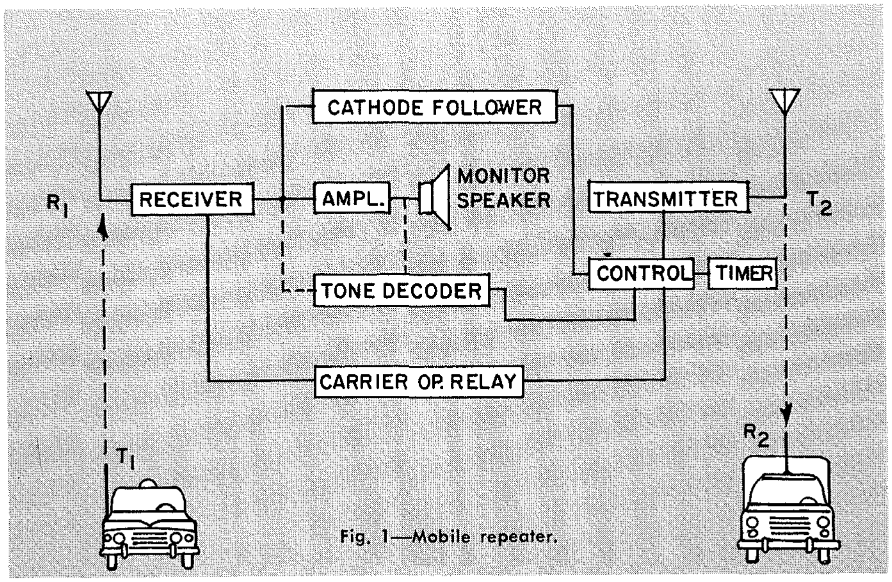


Fig. 1—Mobile repeater.

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THE major limiting factor in the range of a mobile communication system is antenna height. This seriously restricts communication between mobile units, particularly when operating in congested areas where there are high buildings or where the terrain obstructs the radiated signal.

When operating requirements include effective contact between mobile units and fixed locations that do not have appreciable antenna height, the use of a mobile repeater must be considered. Having one location in the area of sufficient height to effectively cover the area permits receiving signals from any unit and repeating the message to any other unit.

The design, installation, and maintenance of a mobile repeater system poses some special problems. These include: 1) *FCC regulations*, 2) *keying*, 3) *audio fidelity*, 4) *desensitization*, 5) *sharing*, and 6) *site layout.*

FCC REGULATIONS

The Rules and Regulations of the Federal Communications Commission (FCC) provide that some applicants are eligible to be licensed to operate a mobile relay station. Anyone contemplating the use of a mobile relay station should refer to the applicable section of the FCC Rules to determine eligibility, in requesting a license to permit the use of a mobile repeater. The applicant must make a strong showing *that no other system will meet his operating requirements.* Since mobile repeaters may only be operated on frequencies above 450 Mc in the Business, Citizens, Manufacturers, and Special Industrial classifications, the discussion here will be mostly confined to this type of system.

A mobile repeater must meet all of the technical standards of a base station. In addition, it must be provided with a coded tone keying system so that it will be actuated only by desired signals and it must be equipped with an automatic timer that limits any keyed-on condition to three minutes.

A mobile communications repeater must transmit on frequencies allocated to base station operation. Close spacing increases the problem of preventing interaction of transmitters and receivers in a repeater system. In setting up a mobile repeater station it is desirable to select a matching mobile transmitting frequency spaced higher by at least 5 Mc. This has not always been possible with the frequencies available for a given service. In some areas different coordinating committees have come up with different solutions. For instance, in Southern California, the spacings are as follows:

20 Business channels, 461.05-462.00; spacing + 6.95 Mc
14 Citizens channels, 462.55-463.20; spacing + 3.25 Mc
20 Business channels, 463.25-464.20; spacing + 5.75 Mc
10 Business channels, 464.25-464.70; spacing + 2.75 Mc

KEYING

The simplest method would be to use the noise quieting action of a receiver signal to operate a relay that keyed the associated transmitter. However, the FCC will not waive the requirement, noted above, for coded tone keying unless the applicant can prove there are no co-channel users within range that could cause undesired keying of the relay. There are two common methods of meeting the coded tone requirement; so-called *beep tones*, and *continuous-tone squelch* systems.

A beep system consists of simple tone oscillators on each mobile and base station unit that emits a short burst of a finite tone (0.33 to 1.0 second, 1,300 to 2,800 cps) whenever the transmitter is keyed. Associated with the repeater receiver is a tone decoder that keys the transmitter when it receives the correct tone continuously for from 0.15 to 0.45 second. The tone persistence and delay is adjustable to prevent false keying by voice frequencies. The decoder is reset at the end of a transmission by using the fallback of a carrier operated relay.

The above represent a relatively simple application of beep tones. Actual operating conditions may require special modifications. When there are no competing systems on the same frequency in the area, it may be desirable to delay the release of the decoder and/or carrier operated relay for as much as 3 seconds so that the repeater hangs on during a rapid exchange of messages between units. However, this creates interference when there are other users. On the other hand, if resetting is instantaneous, a mobile moving in a marginal signal area might lose the repeater in a momentary signal dip. Some delay of release is necessary, and this produces another problem: If the transmitter hangs on during a moment when the receiver is

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not quieted, a noise burst will be transmitted. This now requires that the C.O.R. mute the audio applied to the transmitter when the receiver is not quieted. From the conditions that the repeater must meet, it is obvious that the design of an effective repeater system is *not* simple.

Beep tone equipment may be used to provide a "Quiet Office" function. If the persistence of the tone oscillator is increased and the delay of the repeater decoder reduced, enough of the beep will be retransmitted to activate a decoder that unmutes the speaker of a local station or remote control in a busy office where the customer wants to hear properly coded signals only. Alternately, another tone transmitter can be keyed with the repeater transmitter to provide this function.

If the customer wants general system quieting except on his own calls, it may be preferable to use a continuous tone squelch, such as RCA's *Quiet Channel.* This system uses finite, continuous, reed-controlled tones between 80 and 250 cps. Receiving the proper tone causes the modified Quiet Channel unit associated with the repeater receiver to key the repeater transmitter. Again, it may be necessary to provide some hang-on time for transmitter keying. If a Quiet Channel function is required to control mobile receiver muting, a tone is reinserted at the repeater transmitter.

AUDIO FIDELITY

The major components of human speech occupy the frequency range of 80 to 8,000 cps. The average power of male speech peaks at 500 cps, slopes down to 3,000 cps (−8 db), and then falls off rapidly to the upper limit. If there were no legal or technical limitations, a communications system could be designed to faithfully transmit speech; however, there are such limitations, and the problem here is to design and maintain a system that provides, at least, intelligible speech.

The FCC Rules provide that the upper frequency limit of a mobile communications system shall be 3,000 cps. This limitation was tightened by a newer requirement that all transmitters be equipped with a roll-off filter that shall attenuate greater than the level at 1 kc by the formula 40 $\log_{10}$ $(f/3)$ decibels. In actual practice, this results in very rapid attenuation of frequencies above 2,800 cps.

The FCC rules also specify that each transmitter shall be provided with a device which automatically will prevent modulation in excess of that specified. To meet this requirement, we must use a "brick-wall" type of limiter that positively prevents any audio peak from exceeding that which produces full modulation. The problem, then, is to get the speech level right up against the wall for maximum average volume without affecting too many of the peaks.

The microphone output level follows average male speech which slopes down from a peak at about 500 cps. To bring this curve up so all peak frequencies can be limited, a 6-db-per-octave pre-emphasis circuit is used. Simply stated, this is an RC network, through which when the frequency doubles, the output doubles. Since a phase modulator is used in which the modulation is proportional to frequency, it is important to limit high frequencies which are most likely to overmodulate the transmitter. The signal is then amplified up to the limiting level and any peaks are clipped off in the limiters. After limiting, the signal goes through a de-emphasis network which is simply a transposed RC combination with the opposite characteristic. There are three purposes here:

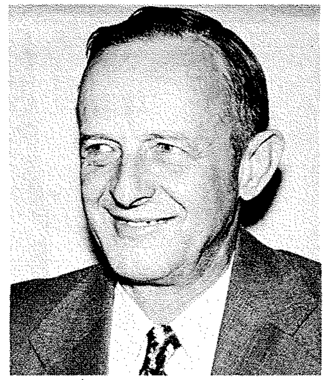
1) to counteract the effect of pre-emphasis and restore the original signal characteristic;
2) to reduce distortion; when the peaks are clipped, distortion is produced by creation of harmonics of the original wave. Harmonics are higher in frequency. Therefore, reducing high frequency response, distortion is reduced.
3) Since the phase modulator has a rising characteristic, if it is driven with a down sloping signal, we will more nearly have true FM in which deviation is not a function of frequency, but only of loudness.

This relatively flat signal will be multiplied, amplified, transmitted and received and demodulated by the repeater receiver. At the discriminator output again de-emphasis is utilized for two reasons:

1) to restore the original downward sloping signal.
2) to reduce noise and distortion, which are both predominantly in the higher frequencies.

The repeater receiver must handle two signals: the *audio intelligence* and the *coded tones* used for keying. Since it is difficult to handle different levels and responses in one amplifier, it is desirable to provide separate paths for each. A small amplifier can take the audio intelligence directly from the discriminator and bring it to a level suitable to modulate the repeater. It is convenient to key this amplifier for noise burst suppression. The regular receiver amplifier is used for tones and monitor speaker operation.

The output of the repeater receiver goes through the audio modulation system of the repeater transmitter in the same manner as outlined above with one notable exception. We have already limited audio excursions in the system mobile and base station units. There is no point then, to drive the repeater into limiting which would only add distortion. In theory, the whole amplifier-limiter string of a repeater transmitter could be eliminated; however, if it received an over deviated signal, it would exceed the modulation limits prescribed in the FCC and be in violation. Therefore, we must set the received level of a fully modulated signal to the edge of limiting so that overmodulated signals are effectively clipped while properly limited signals are faithfully reproduced.



F. C. HARTWICK graduated from the University of California in 1929 with a BS in Business Administration. His thirty years of professional experience includes Service Manager of a radio manufacturing company, owner of an electronic laboratory in San Francisco, Field Engineer for Western Air Lines, RCA Field Engineer assigned to Navy Bureau of Aeronautics, RCA Field Engineer for Mobile Communications, and Administrator of Special Projects in the Mobile-Microwave Engineering Activity of the RCA Service Company. He is now working as Coordinator of Communications Systems Engineering at Meadow Lands, Pennsylvania.

DESENSITIZATION

A major difference between a mobile repeater and a normal mobile communications system is that the receiver and transmitter are operating at the same time. The transmitted signal may effect the sensitivity of the receiver. We must distinguish here between *interference* and *desensitization.* Interfering signals are either directly on-frequency or created by the mixing of other signals; their modulation, if any, may be heard. Desensitizing signals are off-frequency, but so strong that they bias off the front end of the receiver, thus effectively reducing its sensitivity to weak signals.

Desensitization, within a repeater unit, comes from signal leakage out of the transmitter chassis into the receiver chassis and/or by coupling of the transmitting and receiving antennas. Desensitization may also occur from other transmitting units near the site. (Later in this paper, under *Maintenance*, the measurement of desensitization factors will be discussed.)

SHARING

A highly desirable repeater site can seldom be reserved for use by one system only. We may have several users on a single frequency pair. If two or more repeaters are keyed on simultaneously, serious heterodyne interference would result. Since the FCC Rules require coded tone control of repeaters, the simplest solution is to coordinate tone assignments so that each co-channel licensee activates his repeater only with his assigned tone frequency. Two users could still go on the air simultaneously with resulting interference, so it is essential that they monitor to determine that the channel is clear before using. Another solution is to deactivate all but one repeater at a site and attach to it the various tone decoders so that each user can only pick up the repeater when not already in use. This cooperative use may lead to a further arrangement.

Several sites may be available that provide different coverage of areas desired by several customers. We then might have an arrangement where customer *A* provides a repeater at Site 1 and customer *B* at Site 2. They can cooperatively share the advantages of both sites if *A* selects either site with *T1* or *T2* and *B* with *T3* and *T4*. Note we list four tone frequencies on the basis that we are providing Quiet Channel or Quiet Office functions through the repeater. Otherwise only one tone frequency would be required for each site. All of this may sound complicated, but indicates how co-channel users of a repeater pair may operate efficiently. Joint use of transmitting facilities must meet the applicable FCC rules and regulations covering cooperative arrangements.

SITE LAYOUT

When a site must be shared with other users, it is important to prepare an installation plan that will minimize mutual interference and desensitization. Most sites "just grow," with resultant unnecessary interference. Installers should plan jointly the number and type of installations that can be accommodated and where each unit, coaxial run, and antenna should be placed. On sites shared with high-powered TV and/or FM stations, it may be necessary to screen mobile communications equipment rooms.

The following has to be considered at a site:

1) The effect on the radiation pattern of an antenna from other antennas and tower members.
2) The coupling of transmitting and receiving antennas. Generally the least coupling occurs when one antenna is mounted directly over the other so their radiation patterns are concentric.
3) The separation of coaxial runs to prevent coupling.
4) The relative location and ground bonding of equipment housings.
5) Conduit shielding of AC runs.
6) The separation of adjacent channel systems.

One poorly conceived installation can damage the performance of several other systems.

MAINTENANCE

The quality of the signal transmitted by a repeater can be no better than that which it receives from the originating mobile or base station units. Therefore, each unit in a system must be accurately maintained as regards frequency deviation, signal strength, and audio level and quality. Because of the normal limitation of absolute accuracy of field type measuring equipment, the final test of mobile and base station units is by system "netting" procedure. Signal frequency is judged by noting the repeater receiver discriminator DC voltage reading from each unit. Audio voltage readings indicate uniformity of deviation and limiter readings show received signal strength. Audio monitoring reveals level and quality. Units which do not come within reasonable limits on each of these factors should be noted for correction on service schedules.

The highest standard of accurate maintenance must be used on the mobile repeater station since all transmissions between units pass through and are vitally affected by this equipment. The repeater receiver maintains the frequency to which all other transmitters must be netted. All other receivers must be netted to the repeater transmitter.

Fig. 1 illustrates a typical mobile repeater system. A mobile units transmits on the assigned mobile frequency. When this signal is received at the mobile repeater the following sequence occurs. The tone decoder determines that the proper identifying tone code accompanied the mobile signal and it activates the keying circuitry. The carrier operated relay determines that the signal is sufficiently strong to quiet the receiver. The sensitivity adjustment of this circuit establishes the minimum signal to noise ratio that will be retransmitted. The cathode follower amplifier now applies the audio output, from the receiver discriminator, at the proper level, to modulate the repeater transmitter. The timer circuit limits the maximum period of continuous retransmission to the legal limit of three minutes. The retransmitted signal is received by other units in the system.

Fig. 2 shows the keying control circuitry in greater detail. A fast acting relay *5K1* and a slow release relay *5K2* are employed. When a tone decoder determines that the signal is properly identified, its relay energizes the slow release relay *5K2*. This relay resets the decoder, keys the transmitter, and applies power to the fast acting circuit. If the carrier operated relay determines that the signal to noise ratio is adequate for retransmission, its contacts actuates *5K1*. This relay holds in *5K2* and activates the vector type cathode follower amplifier which applies audio to the transmitter. As previously discussed, the delay release time of *5K2* must be sufficient to hold during momentary signal dips, yet not long enough to create excessive channel occupancy. Typical values for delays of 0.5 to 1.0 second would be 10K coil; *R2*, 15K; *R3*, 5K; and *C*, 10 μf. At higher altitudes, a flaring filter (0.1 μf, 20 ohm) across contacts that activate *5K2* may be necessary.

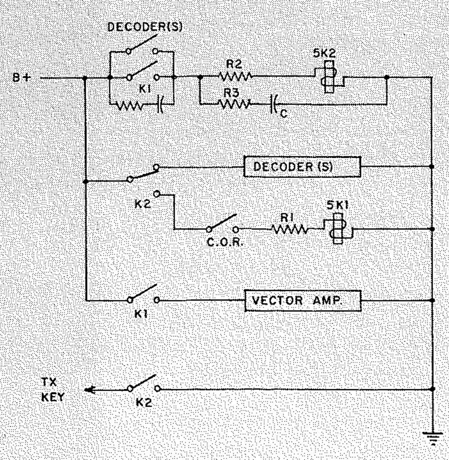


Fig. 2—Repeater keying.

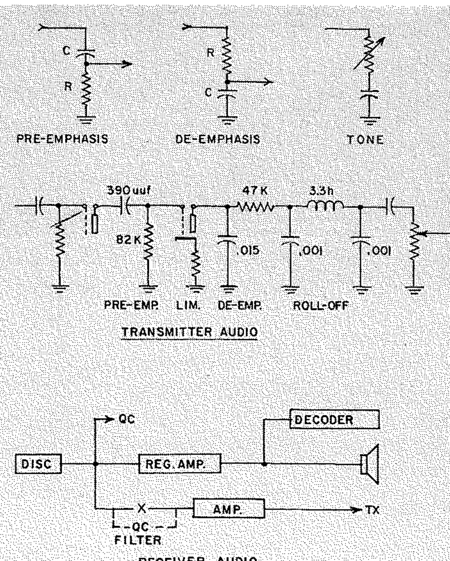


Fig. 3—Repeater audio.

Fig. 3 illustrates some of the audio circuitry involved in repeater operation. The characteristics of pre-emphasis and de-emphasis circuits should be apparent when we note, from a reactance chart, that at 390 pf, capacitor is approximately equivalent to 800K at 500 cps, 400K at 1,000 cps, and 200K at 2,000 cps, or 6 db per octave. Maintaining specified component values in communications equipment audio circuitry is essential in retaining the proper characteristic. Note that these circuits may vary in specific location in various equipment designs. Pre-emphasis may be placed before or after the initial amplification of audio input. The limiters may be biased diodes or saturated amplifiers. The de-emphasis circuit is augmented by a pi or half-section LC roll-off filter as specified by FCC rules. Note that the modulation adjustment is after amplification, limiting, and shaping. An overly common maintenance procedure error is to merely adjust for proper deviation without regard for the overall audio characteristic of the transmitter. Reference levels of sine wave audio input should be established that just limit in a normal audio system. Microphone level and audio-system deficiencies should be corrected rather than attempting to compensate by readjusting the deviation level control.

The repeater receiver audio system is block diagrammed in Fig. 3. While in a normal receiver, only high-level audio to a low-impedance speaker is required, here we have several audio functions: The audio output from the discriminator is fed through the normal audio amplifier to the monitor speaker. If beep tone coding is employed, the decoder's low-impedance input is paralleled with the speaker. Level will be affected if the speaker is switched in and out of the system. If continuous-tone-squelch Quiet Channel equipment is used, it is fed directly from the discriminator. Then, a twin-T notch filter is needed to filter the low-frequency tones out of the retransmitted audio.

To provide the required matching between the high impedance of the discriminator output and the low impedance of the transmitter microphone input, a cathode output amplifier may be used.

To set repeater audio levels, the first step is to determine what sine-wave audio level at the input to the transmitter drives the audio system to the edge of limiting. Using this audio input, deviation is set just within the legally specified limit. Using a signal from one of the system base or mobile units that is fully modulated by the same sine wave tone, the gain control is set on the cathode follower amplifier to deliver the same audio level noted above. This method assures maximum recovered audio with minimum distortion on the retransmitted signal.

DESENSITIZATION TESTS

The amount of receiver desensitization that can be tolerated is a function of the minimum signal that is available in normal system operation.

When the sensitivity of a repeater receiver has been affected by its own or other transmitters, there is a finite method of determining the correction required. Fig. 4 illustrates some of the methods. The effect of direct leakage from a transmitter chassis into an inadequately shielded receiver is measured as shown in *A* of Fig. 4. The transmitter is terminated in a dummy load. The receiver noise quieting sensitivity is measured by a signal generator. The transmitter is then keyed and the noise quieting remeasured to determine if more input signal is required.

Measurement of the amount of coupling between transmitting and receiving antennas is shown in *B*. First, the receiver is calibrated to determine the AGC or limiter reading with, say, 1 μv from the signal generator directly connected. Then, the signal generator is connected to the transmitting antenna and the level increased until the same reading is obtained. The amount of db increase required is noted. This measurement is made at the receiver frequency and is comparative only on how well two antennas are isolated, just as the test in *A* concerned chassis leakage only.

The overall evaluation of the desensitization of a receiver by any transmitter is made by the setup in *C*. Again, the receiver sensitivity is measured as in *A*. Then the transmitter is keyed and noise quieting remeasured. This method also evaluates the effectiveness of a cavity filter in the receive line in reducing desensitization.

The remaining factor is the susceptibility of a receiver to desensitization by an off-frequency signal. This comparative measurement is illustrated in *D* and requires a coaxial attenuator to insert a signal into the receiver and determine at what level receiver sensitivity is affected.

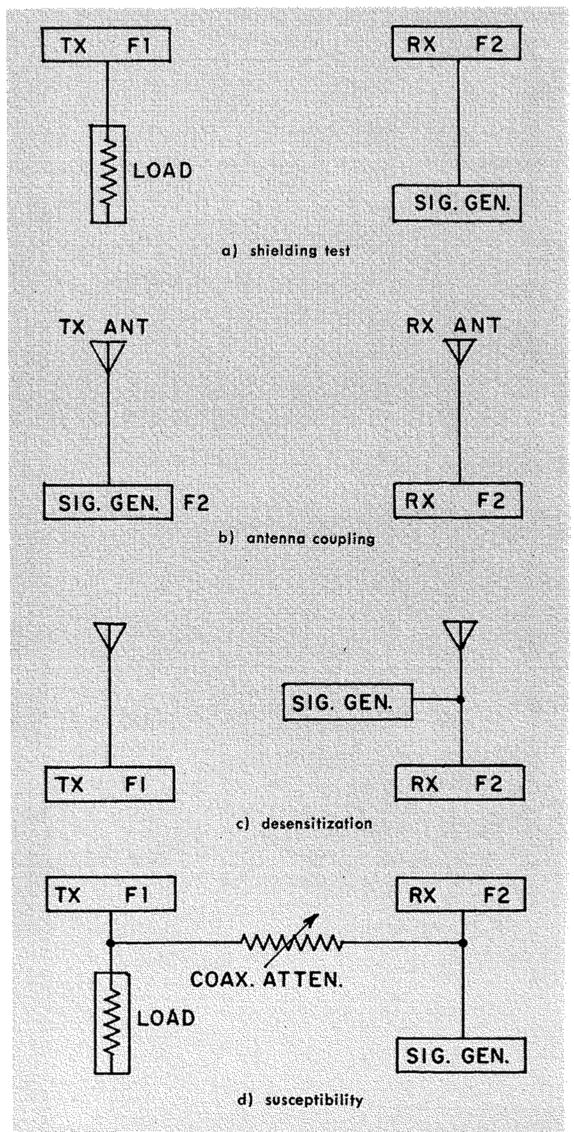
CONCLUSION

Note that the above discussion is concerned with desensitization which is *not always properly recognized* in analyzing system problems. (Interference is covered in other literature.) The principles here apply not only to mobile repeaters but to any receiver operated in high-RF areas. The measurements are comparative in analyzing the source of and/or effectiveness of corrective measures. The objective is to prevent desensitization from degrading the performance of the system below the customers requirements.

To recapitulate, a successful maintenance program for a mobile repeater system requires careful consideration of the following:

1) that tone coding devices be maintained so that the right repeater is consistently opened for customer traffic.
2) that delay release be adequate to hold the circuit open during normal transmissions yet without unnecessary increase of channel occupancy.
3) that the carrier operated relay accurately indicates sufficient carrier quieting to provide an intelligible signal for retransmission.
4) that the originating stations deliver a reasonably undistorted signal and that the repeater faithfully retransmits that audio quality.
5) that all customer users on the channel are aware of the need to monitor the channel to determine that it is clear before starting a series of transmissions.
6) that the repeater is adequately protected from desensitizing and interfering signals to provide reliable communications for the users.

Fig. 4—Desensitization tests.



PERMUTATION CODES

Permutation codes, also known as constant ratio codes, are systems for representing sets of symbols by special sets of binary numbers. These sets of binary numbers have the property that the number of bits equal to zero is constant and the number of bits equal to one is constant.

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The number of different symbols which can be represented by a permutation code using $(m+n)$-bit binary numbers with m bits $= 1$ and n bits $= 0$ is:

$$\frac{(m+n)!}{m!\,n!}$$

In the special case in which $m = 3$ and $n = 2$; there are ten different binary numbers which could be used to represent the ten possible decimal digit values. These ten different binary numbers for $m = 3$ and $n = 2$ are:

00111	*10101*
01011	*10110*
01101	*11001*
01110	*11010*
10011	*11100*

The formula for the number of different symbols which can be represented by a permutation code with (m) *1*'s and (n) *0*'s can be developed by the theory of permutations and combinations.

In a permutation code, it is not possible to assign a constant weight to each bit position. This makes it impossible to establish simple arithmetic rules for permutation codes. It also makes it difficult to determine what correspondences should be established between a set of numbers and their representations in a permutation code. It should also be noted that a permutation code requires more bits to express a given amount of information than a conventional binary code.

However, permutation codes do provide these advantages:

1) The fixed number of *1*'s in each symbol provide a selfchecking feature.
2) Tests for equality between two symbols in a permutation code are simpler than those between symbols in standard binary codes.
3) Decoding matrices are simpler than for standard binary codes.
4) The average DC level of a serial permutation code signal can be fixed at an arbitrary value.
5) The maximum number of bit positions between changes in bit value in serial signals is small.
6) In punched cards, the number of holes per column is fixed.

TESTS FOR EQUALITY

When two binary numbers are tested for equality, it is usually necessary to perform two tests for each bit position. If the binary number A is compared to the binary number B, then each typical bit a of A would be compared to a corresponding bit b of B through this test:

Is it true that $a = 0$ and $b = 1$?
Is it true that $a = 1$ and $b = 0$?

If the answer to either question is affirmative, then bit a of A is not equal to the corresponding bit b of B. If in any bit position, inequality is detected, the numbers are determined to be unequal. Otherwise, they are determined to be equal.

In special cases, it is possible to compare a binary number A with a set of binary numbers $\{B_i\}$, using only one test per bit. If the number A is known to be equal to one of the members of the set $\{B_i\}$ and if the numbers B_i form an ascending sequence, then only the test:

"*Is it true that $a = 1$ and $b = 0$?*"

need be performed. This can be illustrated by an example in which A = *0 0 1* and $\{B_i\}$ = {*0 0 0, 0 0 1, 0 1 0, 0 1 0, 0 1 1, 1 0 0, 1 0 1, 1 1 0, 1 1 1*}. In this case, there is a number in the set equal to A and the numbers in the set form an ascending sequence.

The test has negative answers for all bit positions when A = *0 1 1* is compared with *0 1 1* and *1 1 1*. Since the numbers B_i form an ascending sequence, A will be compared with *0 1 1* before it is compared with *1 1 1*. Thus, A is assumed equal to the first member of the set B_i for which negative test results are obtained in all bit positions. Any member of the set passing the test but not equal to A will contain a *1* in the bit position in which A has the different value *0*. Therefore, this number will be greater than A and therefore will follow the number equal to A in sequence B_i.

It should be noted that if *0 1 1* were not included in the set B_i, the method would fail if *1 1 1* were included in the set. Also, the method requires that the set B_i be arranged to form an increasing sequence.

In a permutation code, it is never necessary to perform more than one test per bit position. The number of *1*'s in each representation of a symbol is constant. Therefore, if two symbols are different, the test:

"*Is it true that $a = 0$ and $b = 1$?*"

will yield affirmative results in some bit position.

Consider a permutation code in which there are m bits equal to *1* and n bits equal to *0* in each representation of a symbol. Then if, in some bit position, $a = 1$ and $b = 0$, there would be $(m-1)$ *1*'s in the remaining bits of A, and (m) *1*'s in the remaining bits of B. Therefore, there must be at least one bit position in which $b = 1$ and $a = 0$, so that the number of *1*'s in A and B can be equalized.

As an example, in the three-out-of-five code previously displayed, consider the numbers A = *1 1 0 1 0* and B = *0 1 0 1 1*. In the bit position furthest left, $a = 1$ and $b = 0$. Inequality obviously exists, but it is not detected by the test of this bit. However, there are two *1's* in the remaining bits of A and three *1's* in the remaining bits of B. Therefore, there must be one bit position in which $a = 0$ and $b = 1$. This is the bit position furthest right. The results of the test for this bit position would indicate that the numbers are unequal. The gates required for testing of two decimal digital are shown in Fig. 1 for both binary coded decimal numbers and permutation coded numbers.

A permutation code can be advantageous in controlling the distribution of objects to a large number of stations. Each object can be placed on a tray to which adjustable cams representing binary digits are attached. Each cam would be in one of two positions to indicate the value of the digit. As the tray passes the various stations, it opens a switch for each bit in which inequality is detected. If, at some station, all bits are equal, the circuit is closed and the object is removed from the tray at the station.

To test for a *1* in the tray bit and *0* in the station bit, a cam-controlled switch would be required if the station bit were a *0*. If the station bit were a *1*, negative test results could be assumed. Similarly, to test for a *0* in the tray bit and a *1* in the station bit, a cam-controlled switch would be required, if the station bit were a *0*. Here again, negative test results can be assumed if the station bit is a *1*. Thus one active cam-controlled switch would be required for each bit position after the station number were established. If the station number were fixed, this would mean one switch per bit per station. If the station number were changeable, it could mean two cam-controlled switches per station with means of bypassing one of the switches to select the bit value.

If the trays were routed so that the station numbers formed an ascending sequence, and if no numbers except station numbers were ever represented by the configurations of tray cams, then only one test per bit position per station would be required. Thus, cam-operated

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switches would be required only in the bit positions in which the station number bit equals *1*. However, if the stations can be rearranged, difficulties would arise. Difficulties might also arise if stations were deactivated.

If a permutation code were used, however, it would still be possible to limit the number of cam-operated switches. Each station number could be represented by switches in those bit positions where the station number bit value is *1*.

When a permutation code is thus used, it should be noted that by increasing the number of bits, it might be possible to reduce the number of bits equal to *1*. For example, a three-out-of-six code could represent 20 different symbols, whereas a two-out-of-seven code could represent 21 different symbols. If there were twenty stations, either code could be used. In the first case, 60 cam-operated switches would be required, whereas in the second case, only 40 cam-operated switches would be required. On the other hand, only 6 cams per tray would be required for the 60-switch system, whereas 7 cams per tray would be required for the 40-switch system.

DECODING MATRICES

In a decoding scheme for a conventional binary number, one diode per bit is required for each output line. For a permutation with (m) *1*'s and (n) *0*'s for each symbol, decoding can be achieved with either m diodes per output line or with n diodes per output line. This is illustrated in Fig. 2. Twenty-four diodes are required to convert a three-bit number to an octal number. Only sixteen diodes are required to convert a three-out-of-five permutation code number to an octal number.

The advantages of this saving in addressing technique in computers are obvious. However, they are offset by the additional bits required to represent an address and by difficulties in modifying addresses.

ELECTRICAL PROPERTIES OF SERIAL SIGNALS

Each symbol representation in a permutation code contains a fixed number of ones and a fixed number of zeros. If a *1* is represented by a voltage level of x volts and a *0* is represented by y volts, then the average voltage for a m-out-of-$(m + n)$ permutation code is:

$$\frac{mx + ny}{m + n}$$

Thus, it is possible to develop any desired DC level in a serial permutation code signal by fixing the voltages x and y accordingly. This means that condensors will charge up to a predictable level and will remain charged to that level.

The serial permutation codes have a useful self-clocking feature. There is a predictable maximum time between one change in signal from *0* to *1* to the next and from one change from *1* to *0* and the next. For example, in a four-out-of-eight code, it is impossible to have more than eight consecutive ones or more than eight consecutive zeros. If a local clock were used to develop strobe pulses for an NRZ stream of four-out-of-eight code information, it could be resynchronized on these frequent changes of bit value. This makes it possible to liberalize the tolerances for the clock.

In the design of a punched-card code, it is desirable to avoid exceeding a maximum number of holes per column. The permutation codes make this possible.

A permutation code with exactly three holes in twelve possible positions of a column can represent 220 different symbols. A permutation code with exactly two holes in each of twelve possible positions can represent 66 different symbols. With one hole, 12 different symbols can be represented.

A three-out-of-twelve permutation code can therefore represent all the symbols representable by a seven-bit conventional binary code.

If a deviation from the permutation code were made so that 0, 1, 2, or 3 holes per twelve-position column were allowed, 299 different symbols could be represented. The number of different symbols which can be represented by not more than three holes in $m + n$ positions is given in Table I.

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TABLE I

$m + n$	*Different symbols represented by not more than three holes*
12	299
11	232
10	176
9	130
8	79
7	64
6	42
5	26
4	15
3	8
2	4
1	2

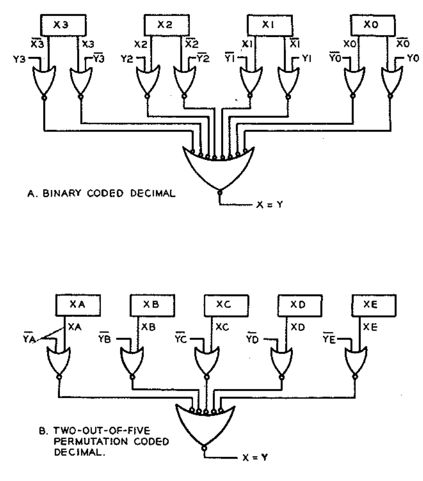
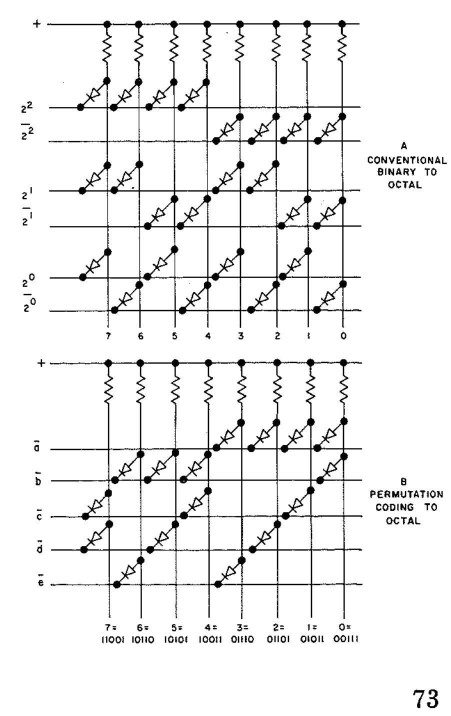


Fig. 1—Equality tests for a parallel decimal digit. In a conventional binary coding, it is necessary to perform two anti-coincidence tests per bit. However, in permutation coding, only one test per bit is required. The permutation code also provides some self checking capability. These advantages are offset by a longer character length.

Fig. 2—Decoding scheme for conventional binary coding and for permutation coding.



ANALYSIS OF THE SHMOO PLOT FOR COINCIDENT CURRENT CORE-MEMORY OPERATION

Magnetic-core-memory circuit-design engineers employ the "current failure bound curves," or "Shmoo" plot, to establish reliable operating conditions for and to evaluate the performance of a computer memory system. This paper offers a qualitative analysis of the boundary conditions of these plots by way of the basic operating equations for a coincident-current memory (CCM) system. The paper shows how the bounds are generated using the four basic inequalities for a CCM, and how these bounds are affected by the magnetic characteristics and the peripheral circuitry. Described is a test system and a procedure to generate Shmoo plots. To illustrate, an ideal Shmoo plot is generated, boundary by boundary, using the operating equations for a theoretical ideal square loop core accessed by ideal circuitry. Then, the B-H characteristics of the ideal core are modified to simulate a more realistic square loop core. Once again a "Shmoo" plot is mathematically generated to show the effects of the core characteristics on the shape and size of the operating region. The equations used to generate this revised plot are also examined to show how they are modified by the core characteristics.

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Fig. 2—Ideal hysteresis loop.

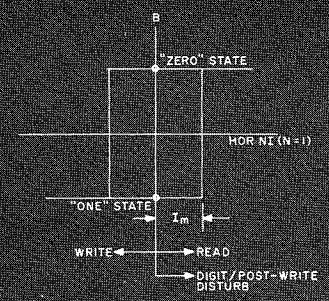


Fig. 3—Timing diagram.

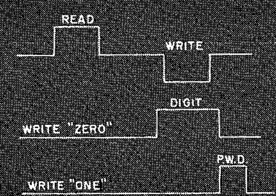
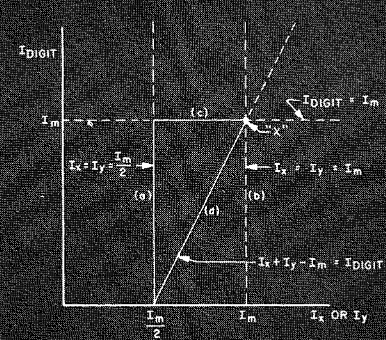


Fig. 4—Ideal shmoo plot.



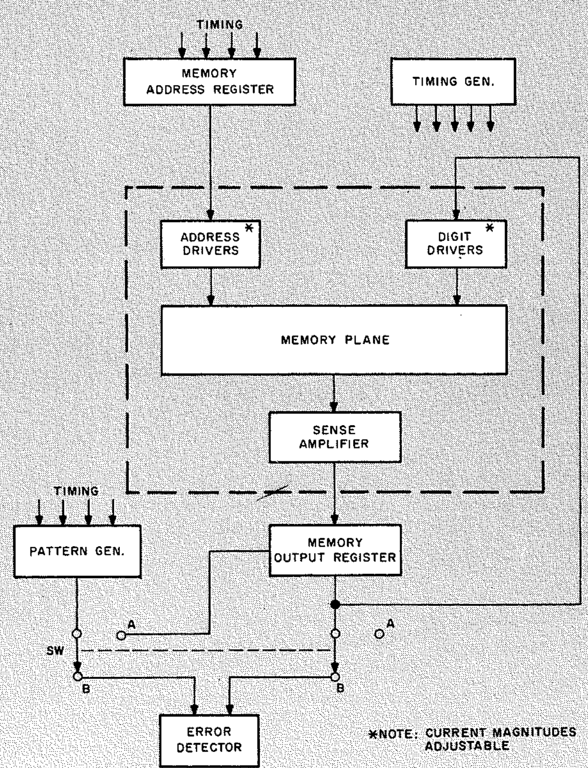


Fig. 1—System diagram for shmoo plot generation.

A "SHMOO PLOT" for a coincident-current memory (CCM), sometimes called the "failure current boundary curves," is a region defining the limits of the drive current, both address and digit currents, within which the system can operate satisfactorily.

The Shmoo plot of a CCM system is generally influenced by the most significant characteristics of the system such as core characteristics, sense circuit capability and drive current tolerances. A Shmoo plot taken under worst-case conditions therefore reflects the reliability of the memory system and can be used to evaluate the magnetic and transistor circuit designs. In a memory system designed to operate over a wide range of temperature, the Shmoo plot plays an important role in optimizing the operating point.

Shmoo plots can also be utilized for Linear-selection memories (LSM). However, the inherent properties of the LSM such as its ability to accommodate wide drive current tolerances and its greater noise discrimination render the Shmoo plots less useful.

The mathematical expression of the Shmoo plot is quite involved because of the nonlinear characteristics of magnetic core material and sensing circuitry. This paper expresses the plot in a set of equations to show its general shape. It is also assumed that the temperature of the memory cores is constant through out the discussion. (The effect of temperature on core characteristics, while quite interesting, will not be considered in this paper.) Above all, only the effect of the magnetic characteristics of the core material on the Shmoo plot is investigated. Other effects due to associated circuitry, such as variation of rise time of drive current, base line shift of sense amplifiers due to variations of pulse rate, or shifting of strobe time will not be considered in this paper.

HOW TO GENERATE A "SHMOO" PLOT

Fig. 1 shows a block diagram of the set-up to generate the Shmoo plot of a memory plane. The blocks inside the dotted lines comprise all the components of the memory system which we wish to evaluate. They are the address drivers, the digit drivers, the memory plane itself and the sense amplifier. Both the address drivers and the digit drivers should have independent control for varying their current magnitude even though they may be designed to track each other in the actual operation.

The system can be explained as follows:

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1) With switch SW in position A, the memory plane is loaded with a pattern, usually the worst-case noise pattern,[1] generated by the pattern generator.
2) The switch in B position operates the memory in a regeneration mode. The contents of the memory is compared bit by bit with the pattern generator.
3) Both the magnitude of the address current (I_x, I_y) and the digit current I_D are varied until an error occurs. The Shmoo plot is made by plotting the limits of digit current vs. address current thus obtained.

AN IDEAL SHMOO PLOT AND ITS BOUNDARIES

As an illustration, let us consider a memory plane made of perfectly square loop core material as shown in Fig. 2. The memory current waveforms are shown in Fig. 3. The post-write disturb, theoretically unnecessary for a perfect square loop core memory, is also shown just for completion of a future discussion. It is assumed that read and write currents are equal in magnitude and that the sense amplifier has a zero threshold. The later is theoretically possible, since there is no *0* signal involved with the perfect square-loop core.

Based upon the above assumptions, it can be easily shown that the memory system will be operative under the following conditions[2] (assume $I_x = I_y$):

$$\frac{I_m}{2} < I_x \text{ or } I_y < I_m \qquad (1)$$

$$I_x + I_y - I_m < I_D < I_m \qquad (2)$$

Where: I_m is the minimum current required to switch a core to its opposite remanent state. There are four inequalities involved and their boundary conditions can be obtained by replacing the inequality signs with "equal" signs thus representing four straight lines as shown by a, b, c and d in Fig. 4. The triangular shaped area enclosed by line a, c and d represents the region of satisfactory memory operation and any operating point either on or outside the boundaries will be shown to be region of memory failure.

The line b for condition I_x or $I_y = I_m$ in Fig. 4 intersects the triangular area only at one point. This is due to the assumption of a perfect square loop material.

Each failure boundary has its own characteristic according to the nature of the failure observed. The failures can only be observed as either a "pick-up" or "loss" of a bit or bits during memory operation. The failure bounds have the following significance:

Line a—Fails read-write *1*'s due to insufficient address current

Line b—Fails read-write *0*'s due to excess address current

Line c—Fails write *1*'s due to excess digit current

Line d—Fails write *0*'s due to insufficient digit current

Case a and b correspond to Eq. 1 during which condition of Eq. 2 must be satisfied. Case c and d corresponding to Eq. 2 during which condition of Eq. 1 must be satisfied. As a convenience in the following discussion, it is assumed that either address current or digit current is being varied while the other is held within specified limits. This is to ensure that the operating point is moving from a point inside the safe region toward the boundaries.

In case a, cores originally in the *1* state will not switch during the read cycle because of insufficient read current, and therefore will not produce an output signal. This is observed by the loss of *1*'s originally stored in the memory. However, all the *0*'s originally stored in the memory will be read out as *0*'s without apparent error.

If a write cycle is initiated, *1*'s can not be written into memory locations where the cores were originally in *0* state because of insufficient write current. Subsequent read-outs will appear as *0*'s.

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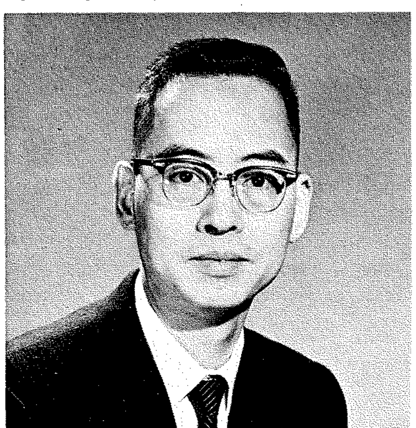

Case b is just the opposite of case a. Cores which are half-selected and are originally in the *1* state will be switched to *0* state during read cycle. Since the sense winding of a CCM is mostly designed to loop all cores in a bipolar fashion, the output induced in the sense winding during the read cycle is the sum of outputs of full-selected core and all half-selected cores which may add to or subtract from each other. The result is observed as erroneous output from all locations of the memory.

During the write cycle, excess write current tends to switch cores both half-selected or full-selected. Therefore, it is incapable of writing *0*'s in any memory locations.

Unfortunately, another type of memory failure (shown as line d in Fig. 4), occurs long before the address current can be raised to I_m unless the digit is also at its maximum value I_m. Therefore, there is only one point, X on Fig. 4, where this type of failure can be actually observed.

Line c represents the boundary beyond which digit current is so large that effective write-*1* operation can not be done to cores which were originally in *0* state. Moreover, the digit current tends to disturb all cores which were originally in the *1* state by switching them into the the *0* state. The same trouble can be caused by the post-write disturb current —usually the same magnitude as that of digit current—even if the digit current is not present as is the case when a *1* is stored in every location of the memory.

The last case is shown by the sloping line d in Fig. 4. This line gives the minimum digit current allowable below which it is too small to cancel the effect of write current for effective write *0* operation.

A MORE REALISTIC SHMOO PLOT

In order to analyze the Shmoo plot in a more realistic manner, we assume that core characteristic can be represented as in Fig. 5. The particular nature of this core material as compared to a conventional core can be characterized by its well defined "knee" point and saturation point. In addition, we assumed the following to make the analysis less complicated (Fig. 5):

1) I_m is the maximum drive current which will switch a core from its remanent state, A, to B. Cores subject to a drive current equal or less than I_m will return to its original remanent state after the removal of drive current.

2) Cores subject to a drive current larger than I_m but less than $I'_m + \Delta I'_m$ will be disturbed from its original remanent state, A, to A' after the removal of the drive current.

3) Cores subject to a drive current equal to or greater than $I'_m + \Delta I'_m$ are considered to be fully switched and will remain in an opposite remanent state E after the removal of the drive current. Remanent state A or E represent the cores in an undisturbed state.

4) The sense amplifier is assumed to have a threshold such that a core switched by a read current equal to $I'_m + \Delta I'_m$ from an undisturbed state will produce a *1* output. Read current below $I'_m + \Delta I'_m$ will not produce an output from the sense amplifier. Signals produced by other drive currents, such as write or digit, are inhibited from getting through the sense amplifier by a strobing technique.

Based on these assumptions, it can be shown that the conditions for satisfactory memory operation corresponding to that described in the previous section are:

$$\frac{I'_m}{2} + \frac{\Delta I'_m}{2} < I_x \text{ or } I_y < I'_m \tag{3}$$

$$I_x + I_y - I'_m - \frac{p}{I_x + I_y} < I_D < (I - K)I'_m + K(I_x + I_y - \Delta I'_m) \tag{4}$$

Terms p and k are modification factors which are functions of the core characteristic as will be explained later.

Eq. 3 represents the limits of address currents. When address current $(I_x + I_y)$ is less than $(I'_m + \Delta I'_m)$, the cores are not fully switched and therefore produce output voltages less than the threshold voltage of the sense amplifier. The boundary condition is represented by a straight line a' in Fig. 6. It is apparent that boundary a' is greatly influenced by the threshold voltage of sense amplifiers. A higher sense amplifier threshold will move a' line along the I_x or I_y axis parallel to its original position to a higher value of I_x or I_y and lower threshold will move a' in the opposite direction. How low the threshold a sense amplifier can be is a design problem determined by the maximum noise level of the system and will not be discussed here.

The upper address current limit is I_m, beyond which cores are disturbed and each produce partial switching outputs which are added algebraically in the sense winding. As mentioned in the previous section, these voltages are either add or subtract thus causing erroneous outputs during read cycle.

Boundary b' is also affected by the sense amplifier threshold in the same manner as boundary a'. However, the effect is far less pronounced due to the fact that partial switching output increases rapidly once the cores are switched beyond their "knee" points in the actual memory.

Eq. 4 can be easily explained by first examining the memory operation along the boundary regions. First, assume the digit current is gradually increased with the total address current maintained at a value slightly greater than $(I'_m + \Delta I'_m)$. A particular memory core originally in the remanent state A, as shown in Fig. 5, will be switched during the read cycle to C and a *1* output is produced as assumed by condition *iv*. If the digit current is increased slightly over I'_m to some value I'_B, this core is now disturbed to B' and returns to a remanent state A'. This can be a result of write-*0* operation at some other memory address or the effect of post write disturb current at this particular memory address. During the subsequent read cycle, a smaller output voltage is produced. This is due to less flux being switched by the same drive current. No output is produced by the sense amplifier. However, the lower core output can be compensated by increasing the address current to some value I'_c at which the core output is large enough to overcome the sense amplifier threshold since the core is being switched faster. This means for each value of digit current greater than I'_m, say I'_B, there exists a limit of address current say I'_c above which the memory will operate satisfactorily. If we define the ratio of the current increments to be K, then:

$$K = \frac{I_D - I'_m}{I_x + I_y - I'_m - \Delta I'_m} \text{ (for } I_D > I'_m) \tag{5}$$

Then, for any value of $I_{DIGIT} > I_m$ there exists a value for K, say K_1, such that if the ratio K is less than K_1, the memory will be operative. If we obtain all values of K for all digit currents and represent them by a function K_D, then:

$$K_D > \frac{I_D - I'_m}{I_x + I_y - I'_m - \Delta I'_m} \tag{6}$$

represents the region of reliable memory operation. Eq. 6 is identical to the second half of Eq. 4, and its boundary condition is shown by line c' in Fig. 6. The maximum amount of digit current increase allowed is shown as δI_D in Fig. 6. The δI_D is usually quite small in comparison with I'_m. This is due to the inherent property of the core material

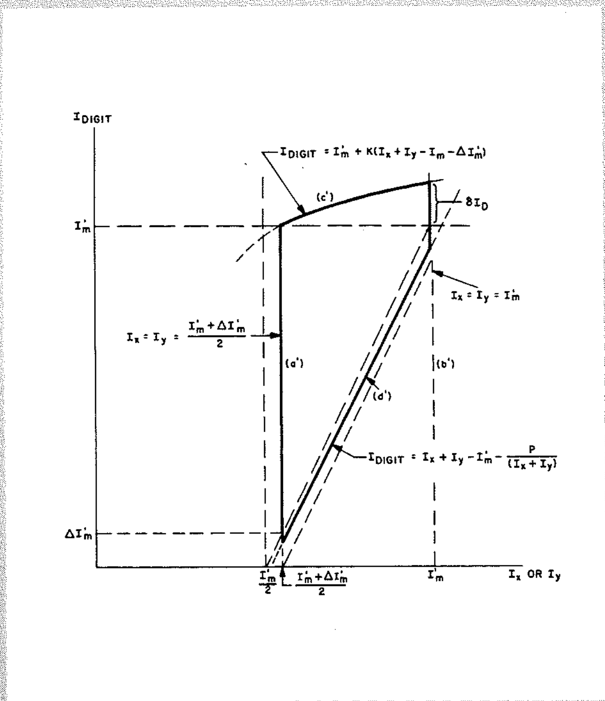

Fig. 5—A more realistic hysteresis loop.

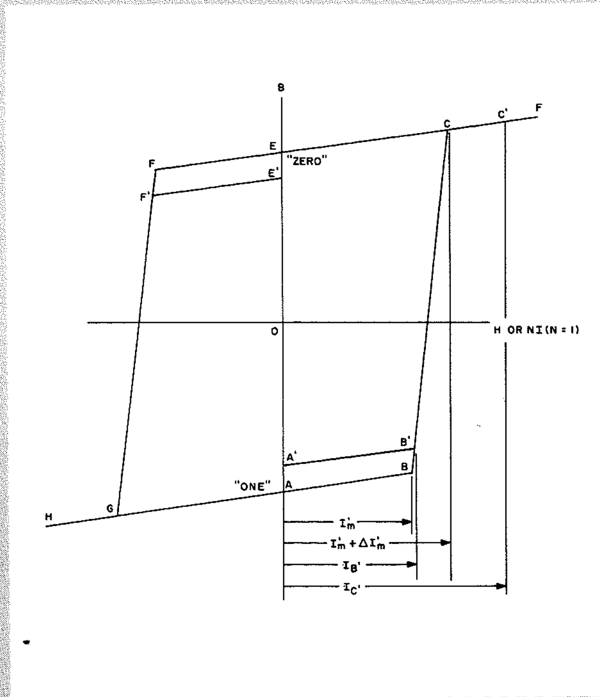

Fig. 6—Shmoo plot based on hysteresis of Fig. 3.

which causes the degree of disturbance of a core to increase sharply once the drive current is large enough to switch it beyond its "knee" point.

Cores originally in the *0* state will also be disturbed. However the degree of disturbance is not so large that subsequent reads will produce *1*'s. Therefore, no memory failure of this nature will be present in the region below line c'.

Last, let us decrease the digit current gradually with the total address current maintained at some nominal value. Cores originally in the *0* remanent state, E, will be disturbed to F' during a write *0* operation. The allowable amount of this type disturbance is inversely proportional to magnitude of the address current. This means a small address current may tolerate large disturbance since the read out voltage is still small enough not to exceed the threshold voltage of sense amplifier. Therefore, we can write the condition as:

$$(I_x + I_y) - I_D - I'_m = \frac{p}{I_x + I_y} \qquad (7)$$

Where: p is function $(I_x + I_y)$. The exact plot of Eq. 7 is difficult, except we know that it is a nonlinear function of I_x, I_y, and I_D. However, we know it lies between two parallel straight lines:

$$(I_x + I_y) - I_D = I'_m + \Delta I'_m$$

(memory definitely inoperative)

$$(I_x + I_y) - I_D = I'_m$$

(memory definitely operative)

which are the extreme conditions of write-*0* operation. The first part of Eq. 4 is obtained by rearranging Eq. 7 and establishing the unequal sign. The boundary condition is shown by curve d' in Fig. 6.

Fig. 7 shows a typical Shmoo plot taken from a CCM system using 4,096 word planes. The correlation between this plot and that of Fig. 6 is quite obvious. For example, line d in Fig. 7 is shown to lie between two parallel lines each characterizing the extreme condition for write-*0* operation as described in the preceding paragraph.

SUMMARY

The operating equation for a magnetic core CCM system can be shown to enclose an area in the I_x or I_y vs. I_D plane. The size and shape of this area is a direct function of the core characteristics, current driver tolerances, and sense amplifier sensitivity. With the techniques described in this paper, the maximum theoretical safe operating region for a particular memory system can be predicted on the basis of the projected circuit and magnetic design expectations. Thereafter, the actual Shmoo plot can be generated via the tests described to reveal any obvious malfunctions in the operating system.

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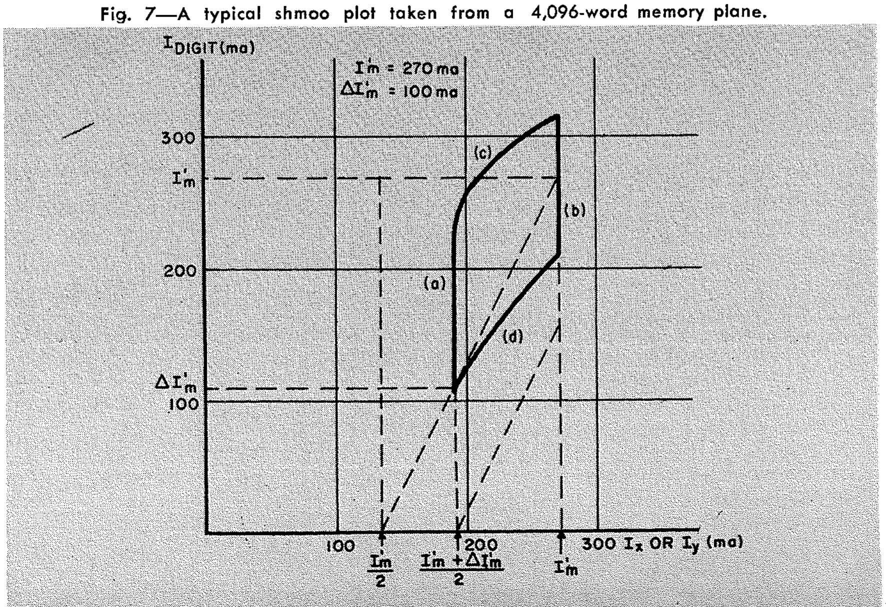
Fig. 7—A typical shmoo plot taken from a 4,096-word memory plane.



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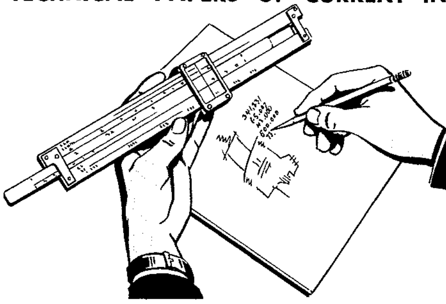


New Information on Legal Restraints on Exportation of Technical Data

C. E. YATES, *RCA Laboratories, Princeton, N. J.*

Two important modifications, effective April 1, 1964, in the export control regulations of the U. S. Department of Commerce were announced subsequent to the publication of the February-March issue of RCA ENGINEER, (Vol. 9, No. 5). These will necessitate changes in the advice contained in my paper "Legal Restraints on the Exportation of Technical Data," on pages 2 through 4 of that issue.

1) The definition of "exportation of technical data" no longer exempts Canada as a foreign country to which the export regulations apply. Hence, the restrictions of General License GTDU (page 4, columns 1 and 2) are applicable to exports of such data to Canada in the same degree that they apply to exports to any other friendly foreign country.
2) Technical data (unclassified and unpublished) relating to any of the commodities listed on the Commerce Department's "Positive List of Commodities or in Supplement No. 2 to Part 371" contained in that Department's "Comprehensive Export Schedule" (which data might otherwise be exportable to Canada and other friendly countries under General License GTDU) *may not now be exported unless the exporter has first received a letter (or agreement) of assurance from the importer with respect to re-exportation.*

The fact these modifications occurred so soon after the publication of my paper illustrates the importance of exporting GTDU technical data through the RCA International Division or, if direct, *only* after consulting with the RCA Law Department. The RCA ENGINEER is not in any position to run continuing articles about changes in the governmental regulations applicable to the exportation of technical data. My paper was intended only to make you aware of the fact that this area is subject to government regulation and not to establish guidelines that could be substituted for exporting technical data through the International Division or upon advice from the Law Department.

As a final cautionary comment, remember that exportation includes the imparting of technical information by word of mouth to visitors from foreign countries. If GTDU technical data are involved, and the visitors represent foreign technical aid licensees, consult in advance with the License Operations Division of RCA International. As to other visitors, consult first with Law Department personnel.

Final manuscript received May 8, 1964.

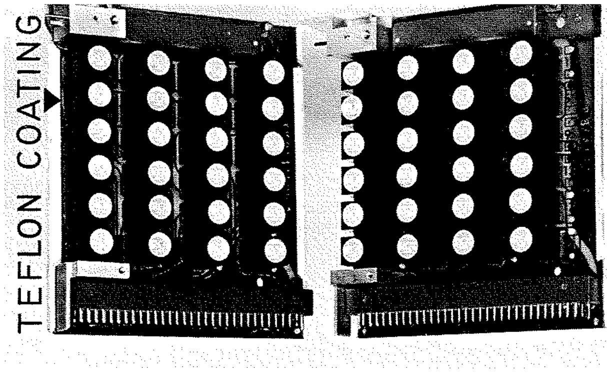


Fig. 1—A 48-module booklet (open).

High-Packing-Density Module Board—Mechanical Aspects

A. C. CORRADO, *Communications Systems Division, DEP, Camden, N. J.*

The design and development in CSD of a compact tactical data processing system required compactness in the packaging of the microcircuitry. Module board design had to be amenable to automatic soldering, high-density connectors, low cost, reliability, standard DEP rack, multilayer circuit card, and mass production.

A 24-micromodule card, meeting the above requirements was developed. This configuration was determined by the logic design of the multilayer cards. The modules, mounted on multilayer cards in an in-line fashion using a 6 x 4 array, are space alternately and, when nested together, make a 48-module booklet (Fig. 1). The in-line method was used because of better adaptability for air flow in the passages. The arrangement of modules in alternate rows also allows the spacing between these modules to be used for printed-wire interconnections.

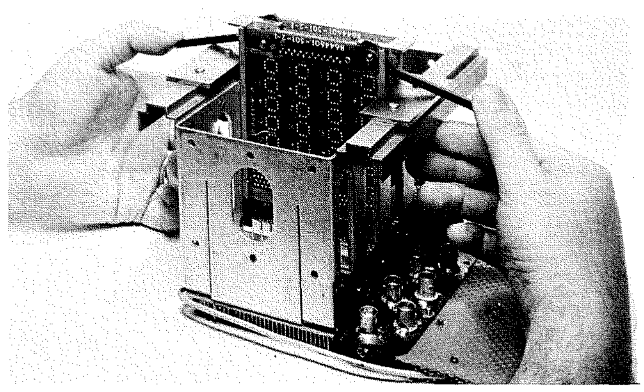
The booklet assembly consists of two independent card assemblies mounted together. When the cards are placed into booklet form, the row of modules on one card meshes into the space of the other mating card. The booklets are disassembled simply by removing four screws; the booklet then opens making the components easily accessible. The booklet assembly is placed in an aluminum chassis with flanges pressed through the act as guides for the booklet. When the booklet is positioned, it is locked in place with springs.

A high-density probe connector accepting a 0.040-inch-diameter probe was developed and incorporated for use in testing and troubleshooting.

Three mechanical innovations developed for use in the 48-module boards are described below:

1) *Extraction Lever:* A set of miniature levers was incorporated in the module booklets to aid in insertion and withdrawal of the booklets into and out of the nest (Fig. 2). The lever became necessary because of use of a miniature 92-pin connector. Because of the large number of pins, the forces needed for insertion and withdrawal were considerably increased. The levers are placed behind the test point connection, taking up a minimum of space.

Fig. 2—Levers for removal of booklets from nest.



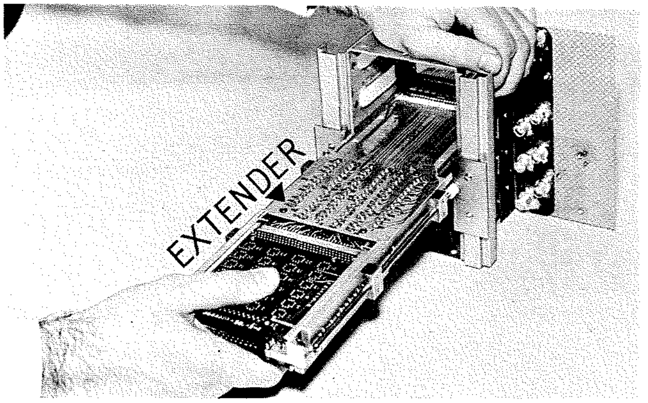


Fig. 3—Card extender and patch board for debugging.

The levers are fabricated from a low-cost extrusion. Lever ratio is approximately 7:1 (mechanical advantage).

2) *Teflon Coating:* The module cards have aluminum frames which act as "rails" for sliding into the booklet nest. To protect the finish of both the cards and the slots in the nests, teflon is sprayed on the rails (Fig. 1). The teflon also acts as a lubricant for insertion and extraction.

3) *Card Extender:* A miniaturized card extender and patch board was developed for easing debugging. The extender is plugged into the nest in place of the module booklet and the booklet is plugged into the extender at the top. Through a jumper arrangement, the booklet is connected to the nest, yet completely exposed and accessible for probing and for breaking and making solder connections (Fig. 3).

Final manuscript received March 6, 1964

High-Power Laser Transmitter

T. NOLAN, *Aerospace Systems Division, DEP, Burlington, Mass.*

A high power laser transmitter has been developed by DEP-ASD, Burlington, Mass. and delivered to MIT Laboratory for Electronics for use in detecting scattering layers in the upper stratosphere (60 to 140 km).

The specified performance consisted of an output energy of ½ joule/pulse at a repetition rate of 1 per second. At the Q switch speed used in this instrument, the peak power per pulse amounted to 10 Mw. (This could have been increased to 50 to 100 Mw; however, the inherent pulse narrowing, accompanying this increase, was considered not desirable in this application.) At the 10-Mw level, the pulse width was 50 nsec.

To attain this performance, a ⅜-by-3½-inch, 0.05%-chrome-doped, 90° ruby was used. The surface of the rod was fine ground to suppress whisper modes. One end was polished to 1/10-wave flatness and perpendicular to the rod axis to close tolerances. The other end was fabricated into a *wedge*, or total internal reflection cut. (A 90° roof prism with its apex centered on the optical axis.)

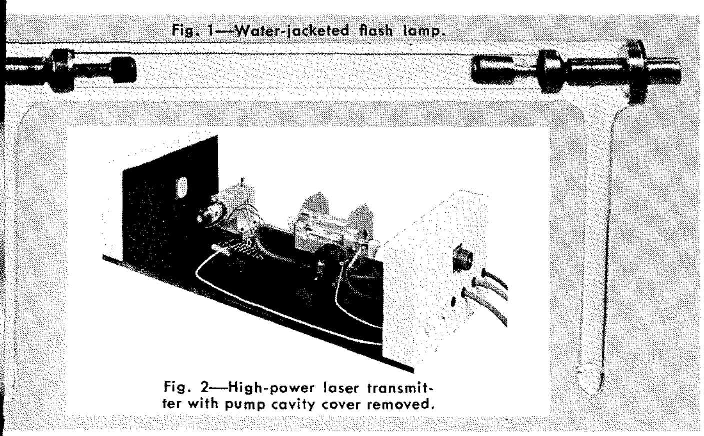


Fig. 1—Water-jacketed flash lamp.

Fig. 2—High-power laser transmitter with pump cavity cover removed.

An RCA-modified EG&G FX-52 xenon flash lamp was used as a pump. The FX-52 is a 3-inch-arc-length xenon flash lamp with heavy-duty electrodes designed for higher repetition rates when used with an air cooling jacket supplied by EG&G. This lamp was purchased, less cooling jacket, and fitted with an RCA-designed water jacket (Fig. 1). This adaptation allowed virtually unlimited operation at 800-to-900-joule input at the desired repetition rate. After 30,000 flashes, the lamp showed no signs of deterioration.

To couple this pump energy into the rod, a high efficiency elliptical cavity was used.[1] The ruby was placed on one focal line of this ellipse and the pump lamp on the other (Fig. 2). This simple geometric configuration allows all of the xenon pump lamp to be focused onto the ruby rod.

The Q control, or Q switch, is evident in Fig. 2 as the unit located in front of the cavity in line with the exit window. The function of this unit is to rapidly change the Q of the system to generate a single giant pulse. The Q switch consists of a spinning mirror driven by a hysteresis synchronous motor and a magnetic pickup.

Functionally, the mirror which has a multilayer dielectric coating peaked for 50% reflectivity at 6,943 angstroms, serves together with the total internal reflection cut on the ruby to form a Fabry-Perot interferometer. When these two elements are in coincidence, and the ruby is pumped over threshold, stimulated emission of coherent light can occur. If the mirror is rotated at higher and higher speeds, the coincident time (i.e. the time that alignment of the interferometer is sufficient for coherent emission) becomes shorter and shorter and higher and higher peak powers are generated. The purpose of the magnetic pickup is to fire the xenon flash lamp at the proper time in this cycle to obtain maximum energy conversion.

To obtain high-repetition-rate operation, considerable cooling of pump lamp and laser rod is necessary. As previously indicated, the xenon pump lamp was outfitted with a water jacket. Fig. 1 shows that not only the quartz envelope is enclosed, but also the end seals. With several thousand volts appearing across these terminals, the use of de-ionized water is mandatory. This was accomplished by passing the water through a simple ion exchanger.

The cooling of the ruby rod was effected by passing dry nitrogen gas through a liquid nitrogen heat exchanger and manifolding it onto the ruby. This same gas was then exhausted through the cavity into a sheet metal housing enclosing the entire unit, and subsequently providing a dry nitrogen atmosphere to prevent windows, ruby faces, etc. from sweating due to condensation and thereby destroying performance.

The equipment performed its function without incident and resulted in some very interesting atmospheric measurements. For a summary of these measurements, see Reference 2.

Acknowledgement: The contributions of N. Luce, T. Haddad, and E. Johnson to this program is acknowledged.

Final manuscript received January 17, 1964

1. T. A. Haddad, "Molding Technique for Elliptical Glass Substrates for Laser Pump Cavities" (*E&R Notes*), RCA ENGINEER 9-6, Apr.-May 1964.

2. Fiocco and Smullen (MIT), "Detection of Scattering Layers in the Upper Atmosphere (60 to 140 km) by Optical Radar," *Nature*, Sept. 28, 1963.

Lightweight Low-Light-Level TV Camera Using 2-inch Image Orthicon

R. J. GILDEA, *Aerospace Systems Division, DEP, Burlington, Mass.*

Recent emphasis on limited warfare has created a strong interest in the ability to detect objects at night. The dark adapted human eye cannot satisfactorily perceive objects of tactical interest under conditions of illumination lower than starlight conditions. Electronic imaging devices offer a number of advantages particularly for airborne applications if reasonably sized units can be attained. These advantages include real time operation, the possibility of immediate strike during an airborne reconnaissance mission, and the ability to provide frame storage at rapid frame rates in the visible spectrum. Until recently, the ability to transmit scenes at low light levels was limited to the 3-inch image orthicon and the bulkier image intensifier orthicon. These devices are very large compared to the less-sensitive vidicon devices and do not lend themselves easily to the development of rugged, portable, and simple equipment. In addition to the requirement for a very sensitive pickup tube, the camera system must be simple to operate, consume little power, and be lightweight for either airborne or portable military applications.

Recent developments in miniaturization of image devices having good performance at low light levels have yielded a camera utilizing a 2-inch image orthicon. The camera consists of a head assembly and a control assembly connected by a multiconductor cable. It is designed to operate with 75 watts input from a source of 25 ± 3 volts. System voltages are developed through a primary regulated converter stage with secondary regulation added for low-voltage supplies. Interlaced scan of 525 lines is generated from a crystal-controlled binary counter. Beam current and focus current regulation is included for more stable operation over a wide range of environmental conditions. The video bandwidth is 10 Mc and sufficient gain is supplied to produce a 1-volt composite video output signal. Aperture correction, high frequency peaking, clamping blanking insertion, and gamma correction circuits are also contained in the amplifier.

The camera development has been slanted toward a reduction in the number of operating controls as well as toward a small and simplified assembly. Outside of the power switch, there are only three operating controls located on the control panel—target voltage, beam current, and electrostatic focus. All other controls are screw driver adjustments accessible only by removing the control cover and usable only for replacement of the image tube.

The resulting camera is an assembly of minimum size and weight, rugged, simple and adaptable to a wide variety of applications and environments. The two-unit concept consisting of the camera head and a separate control unit appears the most adaptable, but the form factors can be varied to a large degree depending upon the space available. The camera head assembly as developed contains the lens, image device, yoke, dynode bleeder assembly, and a preamplifier assembled into a cylindrical package that is 4 inches in diameter and 15 inches long and that weighs 12 lbs. The control unit contains the power supplies, sync generator, deflection amplifiers and the video processing circuits. All circuits are printed circuit modular design that permits greater flexibility and easier maintenance. The control assembly has the circuits mounted in a package 8 x 9 x 12 inches with a weight of 11 lbs. Spare modular slots are provided for the addition of circuits such as dynamic focus and automatic iris. Both assemblies are designed for moderate environmental conditions of 3-g vibration, 0 to 50°C in temperature, and 20,000 feet in altitude.

Although at present the capabilities of the camera in detection under low light levels is limited primarily to the tube sensitivity, *extension of the range is readily possible.* With the addition of an intensifier ahead of the image orthicon at least one magnitude better operation can be obtained. Mechanically this is an extension of 6 inches to the present head assembly but with the same control assembly. The additional length does not affect the flexibility in application of the head assembly.

The control assembly designed is such as to obtain an all-purpose control unit that is capable of operating with most magnetic-type deflection image devices. This is achieved since the control will operate with a 3-inch orthicon or 3-inch intensifier orthicon head of the same electrical configuration. Slight modification will permit operation with vidicon assemblies.

Further miniaturization and reduction in power consumption can still be achieved. This may be accomplished through the use of integrated circuits to reduce the number of printed circuit assemblies. The integrated circuits are readily adaptable for use in the binary counters of the sync generator, as well as the video circuits. Electrostatically deflecting imaging devices would also be advantageous in reducing system weight and power. Many other problems associated with low-light-level television need be solved, but the feasibility of producing miniaturized equipment for use at these levels has been attained through the use of the 2-inch image orthicon.

Final manuscript received February 12, 1964

New Packing Arrangement for Fragile Electronic Equipment

R. E. Hersey, *Communications Systems Division, DEP, Cambridge, Ohio*

[Editor's Note: *The packing design described in this* Note *took second place in the military class at the 15th National Championship Packaging and Handling Competition held in Pittsburgh in November 1963.*]

This 5-piece design replaces a former 18-piece packing for a high-reliability electronic drawer assembly (Fig. 1). The pack is designed for use as a Level A/B Method II, or Level C/C Method III military pack utilizing the same plywood shipping container for either method of pack. The former pack was a conventional plywood box with multiple sections of corrugation and rubberized hair. It is replaced by a Style B plywood shipping container (per PPP-B-601A); two molded curled hair pads per MIL-C-7769, Type IV, extra firm; a water-vapor-proof bag made of MIL-B-131, Class I material; and a waxed Kraft barrier protection wrap. The latter two items are omitted on the Level C/C, Method III military pack, thus affording a three-piece pack. Ten #2 Naven Klimp fasteners are used to secure the shipping container lid.

The new design provides an extremely simple and fool-proof method of packing the delicate electronic drawers. The rubberized hair pads are so moulded to fit the drawer that it is impossible to incorrectly locate the drawer and still be able to close the container. The simplicity of the packing makes for a fast assembly, as well as being economical. The closure of the container is accomplished with Klimp spring steel fasteners which are readily installed or removed by ordinary hand tools. The closure by Klimps makes the container reuseable by the customer for return of drawers for repairs or modification. Prior to this new design packing, the customer had to provide his own packing for return of drawers.

Adoption of this pack represents an *overall savings to RCA of 48%* with the following breakdown: material cost, 36%; labor cost, 60%; weight, 24%; cube, 58%; pieces to handle, 78%. The new design *also affords a 22% cost reduction to the customer* for transportation.

The new pack surpasses the rough handling requirements of MIL-P-116D and MIL-P-7936A. When dropped on each of its eight corners from a height of 30 inches, the maximum shock registered within the pack was only 36 g (Minneapolis-Honeywell Visicorder.) This test was performed under the supervision of the USAF Packaging Specialist at the facilities of the Janesville Packaging Division of Janesville Cotton Mills at Norwalk, Ohio.

For further details on this packing technique, contact the author.

Final manuscript received February 3, 1964

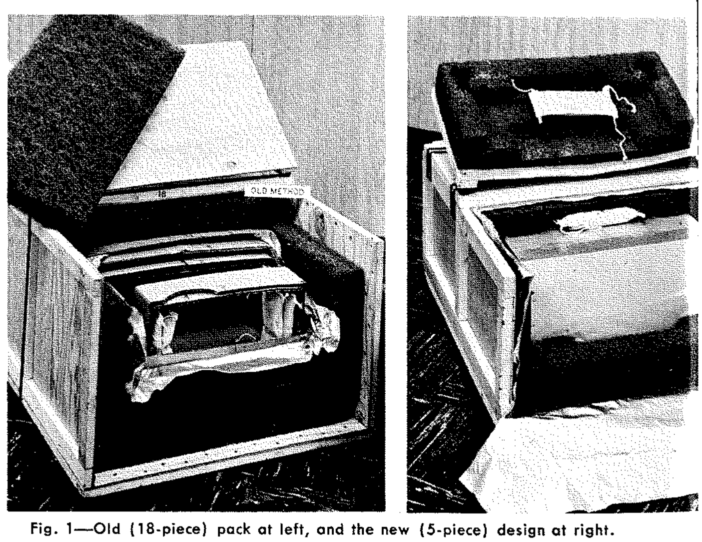


Fig. 1—Old (18-piece) pack at left, and the new (5-piece) design at right.

Patents Granted
TO RCA ENGINEERS

As Reported By RCA Domestic Patents, Princeton

DEFENSE ELECTRONIC PRODUCTS

3,114,137—Dual String Magnetic Shift Register, December 10, 1963; W. L. Morgan, II (Assigned to U.S. Gov't.)

3,115,625 — Coder and Decoder for Radar Type Signals, December 24, 1963; A. Reich (Assigned to U.S. Gov't.)

3,117,575—Ear Protector, January 14, 1964; R. M. Carrell, W. F. Meeker, and M. L. Touger (Assigned to U.S. Gov't.)

3,130,371—Pulse Amplitude Slicing Circuit, April 21, 1964; W. O. Copeland

3,131,312—Circuit for Linearizing Resistance of a Field-Effect Transistor to Bidirectional Current Flow, April 28, 1964; F. L. Putzrath

RCA LABORATORIES

3,124,653—Radio Signal Receivers, Mar. 10, 1964; J. O. Schroeder

3,124,677—Comparator Utilizing Threshold Organs, Mar. 10, 1964; H. S. Miiller

3,125,689—Tunnel Diode Logic Circuits Employing A Single Tunnel Diode for Reset, Mar. 17, 1964; J. C. Miller

3,125,725—Frequency Converter, Mar. 17, 1964; K. K. N. Chang

3,127,567 — Negative Conductance Diode Amplifier, Mar. 31, 1964; K. K. N. Chang

3,127,574—Biasing Circuits for Voltage Controlled Negative Resistance Diodes, Mar. 31, 1964; H. S. Sommers, Jr.

3,128,345—Limiter Control System for Stereophonic Radio Receiver, Apr. 7, 1964; L. A. Freedman and J. O. Presisig

3,130,264—Tuning System, Apr. 21, 1964; W. F. Dietz

3,131,096 — Semiconducting Devices and Methods of Preparation Thereof, Apr. 28, 1964; H. S. Sommers, Jr.

ELECTRON COMPONENTS AND DEVICES

3,124,489—Method of Continuously Growing Thin Strip Crystals, Mar. 10, 1964; F. L. Vogel, Jr. and E. F. Cave

3,124,670—Reed Switch Having Improved Reed Positioning Means, Mar. 10, 1964; G. M. Rose, Jr.

3,124,820—Device for Cleaning Internal Tubular Surface, Mar. 17, 1964; M. D. Berry

3,127,186 — Friction Device and Method, Mar. 31, 1964; M. Van Renssen

3,127,226 — Pin-hole Evaporation Camera, Mar. 31, 1964; C. W. Rector

3,127,537 — Cathode Mount and Alloy Therefor, Mar. 31, 1964; C. W. Horsting

3,128,407—Cathode Grid Assembly for Electron Guns, Apr. 7, 1964; C. H. Mattson

3,128,733—Brazing Jig for Electron Tube Fabrication, Apr. 14, 1964; G. A. Lalak

3,130,485—Apparatus for Extracting Tube Mounts from Assembly Jigs, Apr. 28, 1964; W. A. Preuss

3,130,757—Method of Fabricating Grid Electrodes, Apr. 28, 1964; H. F. Schellack

ELECTRONIC DATA PROCESSING

3,131,316—Threshold Circuit Utilizing Series Capacitor-Diode Combination and Employing Diode Clamp to Maintain Information Transmission, Apr. 28, 1964; G. Glaz

3,133,206—Logic Circuit Having Bistable Tunnel Diode Reset by Monostable Diode, May 12, 1964; R. H. Bergman, E. C. Cornish, and M. M. Kaufman

HOME INSTRUMENTS DIV.

3,132,284—Flyback Transformers, May 5, 1964; F. E. Brooks

BROADCAST AND COMMUNICATIONS PRODUCTS DIV.

3,133,257—Oscillator with Triggerable Phasing, May 12, 1964; J. E. Palmer and J. T. Swaim

RCA VICTOR CO., LTD.

3,133,284—Paraboloidal Antenna with Compensating Elements to Reduce Back Radiation into Feed, May 12, 1964; R. F. Privett, P. Foldes, and S. Komlos

DATES and DEADLINES

Professional Meetings and Calls for Papers

Meetings

June 29-July 2, 1964: First Ann. Mtg. and Tech. Display of the American Institute of Aeronautics and Astronautics; Sheraton Park Hotel, Wash., D.C. *Prog. Info.:* F. A. Cleveland II, Prog. Chairman, AIAA, 2 E. 64th St., N.Y., N.Y.

July 6-10, 1964: Intl. Conf. on Magnetic Recording, Region 8, IEE, BIRE; London, England. *Prog. Info.:* IEE, Savoy Place, London, W.C. 2, England.

July 13-15, 1964: Rochester Conf. on Data Acquis. and Proc. in Biology and Medicine, IEEE, Univ. of Rochester; Univ. of Rochester, Med. Center, Rochester, N.Y. *Prog. Info.:* K. Enslein, 42 E. Ave., Rochester, N.Y.

July 20-24, 1964: Special Tech. Conf. on Nuclear Radiation Effects, PTG-NS, Univ. of Washington; Univ. of Wash. *Prog. Info.:* A. W. Snyder, Rad. Eff. Dept. 5320, Sandia Corp., Albuquerque, N.M.

August 25-28, 1964: 1964 Wescon Show and IEEE Summer and Genl. Mtg., IEEE-WEMA; Sports Arena, Los Angeles, Calif. *Prog. Info.:* Dr. R. R. Bennett, Suite 1920, 3600 Wilshire Blvd., Los Angeles, Calif.

Sept. 1964: Digital Process Control, IEEE, AIAA, ISA, ASME, AICE, IFIP; Stockholm, Sweden. *Prog. Info.:* W. E. Miller, Monsanto Chemical Co., 800 N. Lindbergh Blvd., St. Louis 66, Missouri.

Sept. 1964: Component Parameters and Characteristics, IEEE, AIAA, ISA, ASME, AICE, IMEKO; Stockholm, Sweden. *Prog. Info.:* Prof. H. R. Weed, EE Dept., Ohio State Univ., Columbus 10, Ohio.

Sept. 7-11, 1964: Intl. Conf. on Microwaves, Circuit Theory and Inf. Theory, IECE of Japan, et al; Akasaka Prince Hotel, Tokyo, Japan. *Prog. Info.:* Dr. K. Morita, % IECE of Japan, 2-8 Fujimicho, Chiyoda-Ku, Tokyo, Japan.

Sept. 14-16, 1964: Intl. Convention on Military Electronics (MIL-E-CON 8), PTG-MIL; Shoreham Hotel, Wash., D.C. *Prog. Info.:* Dr. H. M. O'Bryan, Bendix Corp., 1730 K St., N.W., Wash., D.C.

Sept. 17-18, 1964: 12th Ann. Eng. Management Conf., IEEE-ASME, et al; Pick-Carter Hotel, Cleveland, Ohio. *Prog. Info.:* J. Fox, PIB, 333 Jay St., Bklyn. 1, N.Y.

Sept. 14-19, 1964: The 3rd Intl. Measurement Conf., IMEKO III, The 6th Intl. Instruments and Measurements Conf. I and MVI; The Congress Halls at Folkets Hus, Stockholm. *Prog. Info.:* Instrument Soc. of America, 313 6th Ave., Pittsburgh 22, Pa.

Sept. 22-23, 1964: 1st Natl. Conf. on Automotive Electrical and Electronic Eng., PTG-IECI, S.E. Mich. Sec., Univ. of Mich., et al.; Mc Gregor Memorial Center, Wayne State Univ., Detroit, Mich. *Prog. Info.:* E. A. Hanysz, Genl. Motors, Tech. Center, Warren, Mich.

Sept. 22-24, 1964: PTG. on Antennas and Propagation Intl. Symp., PTG-AP; Intl. Hotel, Kennedy Intl. Airport, L.I., N.Y. *Prog. Info.:* Dr. Henry Jasik, Jasik Labs., 100 Shames Dr., Westbury, N.Y.

Sept. 23-24, 1964: 13th Ann. Industrial Electronics Symp., IEEE, PTG-IECI; Phila., Pa. *Prog. Info.:* IEEE Headquarters, Box A, Lenox Hill Station, N.Y. 21, N.Y.

Sept. 24-26, 1964: 14th Ann. Symp. on Broadcasting, PTG-B; Wash., D.C. *Prog. Info.:* IEEE Headquarters, Box A, Lennox Hill Station, N.Y. 21, N.Y.

Sept. 25-26, 1964: 3rd Canadian Symp. on Communications, Montreal Sec. IEEE and Region 7; Queen Elizabeth Hotel, Montreal, Que., Canada. *Prog. Info.:* F. G. R. Warren, P.O. Box 802 Sta. B, Montreal, Que.

Sept. 28-29, 1964: 1st Intl. Congress on Inst. in Aerospace Simul. Facilities, PTG-AS, AGARD; Paris, France. *Prog. Info.:* P. L. Clemens, VKF/AB, Arnold Air Force Sta., Tenn.

Sept. 28-30, 1964: Natl. Conf. on Tube Techniques, Office of the Director of Defense, Research, and Engineering; W. Union Auditorium, 60 Hudson St., N.Y. *Prog. Info.:* Program Sec'y, Mr. D. Slater, Advisory Group on Electron Devices, 346 Broadway, 8th Floor, N.Y., N.Y.

Sept. 30-Oct. 2, 1964: 11th Natl. Vacuum Symp., American Vacuum Soc.; Pick-Congress Hotel, Chicago, Ill. *Prog. Info.:* Dr. G. H. Bancroft, Bendix-Balzer Vacuum Co., Inc., 1645 St. Paul St., Rochester, N.Y.

Calls for Papers

Sept. 22-23, 1964: 1st Natl. Conf. on Automotive Elec. and Electronics Engineering, PTG-IECI, S.E. Mich. Sec., Univ. of Mich., et al.; McGregor Memorial Center, Wayne State Univ., Detroit, Mich. **Deadline:** 500-1,000 wd. abstract, **7/15/64.** *TO:* E. A. Hanysz, Chairman of Papers Committee, Genl. Motors Co., Warren, Mich.

Sept. 30-Oct. 2, 1964: 11th Natl. Vacuum Symp., American Vacuum Soc.; Pick-Congress Hotel, Chicago, Ill. **Deadline:** **July 1, 1964.** *TO:* Dr. G. H. Bancroft, Bendix-Balzer Vacuum Co., Inc., 1645 St. Paul St., Rochester, N.Y.

Oct. 1964: Symp. on Optical Information Processing, PTG-EC, Boston Section, ONR; Boston, Mass. **For Deadline Info.:** A. Vanderburgh, MIT Lincoln Lab., B-115, Lexington, Mass.

Oct. 5-7, 1964: 10th Ann. Comms. Symp., PTG-CS; Utica, N.Y. **Deadline:** Abstracts, approx. **6/1/64,** manuscripts, approx. **9/1/64.** *TO:* IEEE Headquarters, Box A, Lenox Hill Station, N.Y. 21, N.Y.

Oct. 19-21, 1964: Natl. Electronics Conf., IEEE, et al; McCormick Place, Chicago, Ill. **Deadline:** Abstracts, approx. **5/15/64;** manuscripts, **8/1/64.** *TO:* Natl. Elec. Conf., 228 N. LaSalle St., Chicago, Ill.

Oct. 28-30, 1964: Soc. for Experimental Stress Analysis Ann. Mtg. and Exposition; Hotel Manager, Cleveland, Ohio. **For Deadline Info.:** SESA, 21 Bridge Sq., Westport, Conn.

Oct. 28-30, 1964: 11th Nuclear Science Symp.; Instrum. in Space and Lab, IEEE, NASA, AEC, Phila., Pa. **Deadline:** Abstract, 100-300 wds., **July 1, 1964.** *TO:* W. A. Higinbotham, 11th NSS Program Chairman, Brookhaven Natl. Lab., Upton, Long Island, N.Y.

Oct. 29-30, 1964: Electron Devices Mtg., PTG-ED; Sheraton-Park, Wash., D.C. **Deadline:** Abstracts, approx. **8/1/64.** *TO:* IEEE Headquarters, Box A, Lenox Hill Station, N.Y.

Nov. 4-6, 1964: NEREM (Northeast Elec. Res. and Eng. Mtg.) IEEE; Boston, Mass. **Deadline:** Abstract and Summary, **7/1/64.** *TO:* IEEE Boston Office, 313 Wash. St., Newton 58, Mass.

Nov. 9-10, 1964: Optical and Electro-Optical Inf. Proc. Technology Symp., PTG-EC, ACM, OSA, ONR; Statler Hilton, Boston, Mass. **For Deadline Info.:** Mrs. B. McKinney, Computer Assoc. Inc., Lakeside Office Park, Wakefield, Mass.

Nov. 9-11, 1964: Radio Fall Mtg., IEEE-EIA; Hotel Syracuse, Syracuse, N.Y. **For Deadline Info.:** V. M. Graham, EIA, Eng., Dept., 11 W. 42nd St., N.Y., N.Y.

Nov. 16-18, 1964: 17th Ann. Conf. on Eng. in Medicine and Biology, IEEE-ISA, PTG-BME; Cleveland-Sheraton Hotel, Cleveland, Ohio. **Deadline:** Abstracts, approx. **8/1/64.** *TO:* Dr. Peter Frommer, Cincinnati Genl. Hospital, Cincinnati 29, Ohio.

Nov. 16-18, 1964: Space Simulation Testing Conf., AIAA, PTG-AS; Pasadena, Calif. **For Deadline Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N.Y. 21, N.Y.

Nov. 16-19, 1964: 10th Conf. on Magnetism and Magnetic Matls., IEEE, AIP; Paddison Hotel, Minneapolis, Minn. **Deadline:** Abstracts, approx. **8/19/64.** *TO:* J. D. Goodenough, Lincoln Labs., Lexington 73, Mass.

Dec. 3-4, 1964: 15th Ann. Vehicular Comm. Symp., PTG-VC; Cleveland-Sheraton, Cleveland, Ohio. **Deadline:** Abstracts, approx. **9/1/64.** *TO:* R. E. Bloor, Ohio Bell Tel. Co., 700 Prospect Ave., Cleveland Ohio.

(Late 1964): Systems Eng. for Control System Design, IEEE, AIAA, ISA, ASME, AICE; Tokyo, Japan. **For Deadline Info.:** Prof. Henry M. Paynter, ME Dept., Mass. Institute of Tech., Cambridge 39, Mass. and Mr. Harold Chestnut, Genl. Electric Co., One River Rd., Schenectady 5, N.Y.

(Late 1964): Automatic Control in the Peaceful Uses of Space, IEEE, AIAA, ISA, ASME, AICE; Oslo, Norway. **For Deadline Info.:** Dr. J. A. Aseltine, Aerospace Corp., PO Box 95085, Los Angeles, Calif.

Jan. 6-8, 1965: 13th Ann. Industrial Elec. and Control Instrumentation Conf., PTG IECI, ASME-ISA, Phila. Sect.; Phila., Pa. **For Deadline Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N.Y. 21, N.Y.

Jan. 12-14, 1965: 11th Ann. Symp. on Reliability and Quality Control, IEEE-ASQC; Fountainbleu Hotel, Miami Beach, Fla. **Deadline:** Abstracts, **5/1/64,** manuscripts, **7/14/64.** *TO:* H. E. Reese, Burroughs Corp., Military Systems Div., Box 305, Paoli, Pa.

Feb. 3-5, 1965: 6th Winter Convention on Military Electronics, PTG-MIL L.A. Sect.; Ambassador Hotel, Los Angeles, Calif. **For Deadline Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N.Y. 21, N.Y.

Feb. 17-19, 1965: Intl. Solid State Circuits Conf., IEEE, PTG-CT, Univ. of Pa.; Phila., Pa. **Deadline:** Abstract, approx. **11/1/64.** *FOR INFO.:* IEEE Headquarters, Box A, Lenox Hill Station, N.Y. 21, N.Y.

March 22-25, 1965: IEEE International Convention, All PTG's; Coliseum and New York-Hilton, New York City, N.Y. **Deadline:** Abstracts, approx. **10/19/64.** *FOR INFO.:* IEEE Headquarters, Box A, Lenox Hill Station, N.Y. 21, N.Y.

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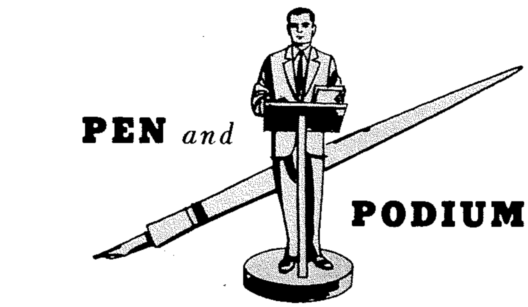

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Both published papers and verbal presentations are indexed. To obtain a published paper, borrow the journal from your library—or write or call the author for a reprint. For information on verbal presentations, write or call the author. This index is prepared from listings provided bimonthly by divisional Technical Publications Administrators and Editorial Representatives—who should be contacted concerning errors or omissions (see inside back cover).

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High-Field Superconducting Magnets by Magnetic-Field Stabilization—E. R. Schrader, N. S. Freedman (ECD-Pr.) *Applied Physics Letter*, Mar. 15, 1964

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Synchronization of TV-Pictures by an Audio Frequency (AudLok)—J. L. Hathaway (NBC, N.Y.) Engineers Mtg., NAB Conv., Chicago, Apr. 6, 1964

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Camera, A New Ultraportable TV—J. Castleberry, (DEP-CSD, Cam.) J. L. Wilson (NBC, N.Y.) Nat'l. Assoc. of Broadcasters, Chicago, Apr. 6, 1964

Camera Developments, A Report on Color TV—H. N. Kozanowski, K. Sadashige (BCD, Cam.) NAB, Chicago, Ill., Apr. 7, 1964

Cartridge Tape Design to Meet NAB Recording and Reproducing Standards—C. B. Meyer (BCD, Cam.) Nat'l. Assoc. of Broadcasters, Chicago, Ill., Apr. 8, 1964

Preamplifier, Television Camera, A Study of Noise in—K. Sadashige (BCD, Cam.) *Journal of SMPTE*, Mar. 1964

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Nuvistors, VHF Applications of—R. M. Mendelson (ECD, Hr.) East Coast VHF Society, Paterson, N.J., Mar. 15, 1964

Transmitting Tube for the RELAY Satellite—M. Nowogrodzki (ECD, Hr.) New Hyde Park, Jewish Center, Long Island, N.Y., Mar. 8, 1964

Traveling-Wave Tube, Design and Performance of an Electrostatically Focused 5-kw X-Band—E. Belohoubek, F. E. Vaccaro, W. W. Siekanowicz (ECD, Pr.) *IEEE Transactions on Electron Devices*, Mar. 1964

Traveling-Wave-Tube Noise Figures of 1.0 db at S-Band—J. M. Harrer, E. E. Thomas (Labs, Pr.) *Proceedings of IEEE*, Feb. 1964

TUBE MATERIALS; THEORY

Tracer Studies of Impurity-Doped Oxide Cathodes—J. K. Lee (ECD, Marion, Ind.) Oak Ridge Radioisotope Conf., Tenn., Apr. 1964

AUTHOR INDEX

Subject listed opposite each author's name indicates where complete citation to his paper may be found in the subject index. Where an author has more than one paper, his name is repeated for each.

RCA VICTOR CO., LTD.

RCA SERVICE COMPANY

NATIONAL BROADCASTING CO., INC.

RCA RECORD DIVISION

DEP AEROSPACE SYSTEMS DIVISION

DEP CENTRAL ENGINEERING

DEP ASTRO-ELECTRONICS DIVISION

DEP APPLIED RESEARCH

DEP MISSILE AND SURFACE RADAR DIV.

DEP COMMUNICATIONS SYSTEMS DIV.

BROADCAST AND COMMUNICATIONS PRODUCTS DIV.

ELECTRONIC COMPONENTS AND DEVICES

RCA LABORATORIES

Engineering NEWS *and* HIGHLIGHTS

FOUR RECEIVE LABS DOCTORAL STUDY AWARDS FOR 1964-1965

The RCA Laboratories *Doctoral Study Award* was adopted as a supplement to the *David Sarnoff Fellowships* and is consistent with the Laboratories' policy of encouraging technical staff members to continue graduate study in fields related to their present or anticipated assignments with RCA. The Award recipients are given full-time leave for graduate study with the Laboratories providing half salary, tuition, fees, and a book allowance. The 1964-65 recipients are:

Larry J. French, member of the technical staff of the Computer Research Laboratory, joined the Laboratories in June, 1962, after receiving his BEE from Pratt Institute. He will receive his MSEE from the Polytechnic Institute of Brooklyn in June and plans to continue studies for his Ph.D. in EE at Brooklyn.

Mrs. Joan Lurie joined the Astro-Electronics Applied Research Laboratory in July 1962 after having received a BS in physics from Brooklyn College and an MS in physics from Rutgers University. She plans to attend Rutgers to pursue doctoral work in Physics.

David H. Vilkomerson, a member of the technical staff of the Computer Research Laboratory, transferred to the Laboratories from DEP-Moorestown in February, 1963. He received his BSEE from M.I.T. and will receive his MSEE from the University of Pennsylvania on the Graduate Study Program. He plans to continue his doctoral studies in electrical engineering at Columbia University.

Albert Waxman of the Electronic Research Laboratory was employed in February, 1962. He is a BSEE graduate of the City College of New York and will receive his master's degree in electrical engineering from Princeton University this June. He plans to continue at Princeton for a Ph.D. in electrical engineering.

FIRST PRODUCTION OF RCA COLOR TV TUBES OUTSIDE U.S. TO BE BEGUN IN CANADA BY RCA VICTOR COMPANY, LTD.

RCA Victor Company, Ltd., will begin output in 1964 of the first RCA color television picture tubes to be produced outside the United States. **John D. Houlding,** President of RCA Victor Company, Ltd., said in Montreal that production would start in the third quarter of this year on a new assembly line at Prescott, Ontario. The plant now produces four models of RCA Victor color television receivers.

Mr. Houlding said that RCA Victor's total investment for plant and manufacturing facilities for color picture tubes at Prescott will exceed $1 million over the next two years. He estimated that the Prescott plant is expected to have sufficient capacity to meet RCA Victor's own requirements and to supply tubes to other manufacturers in Canada.

No other Canadian company manufactures either color tubes or color television receivers.

OBERT HONORED AS "OUTSTANDING ALUMNUS"

M. J. Obert of the Home Instruments Division has been chosen as the recipient of an award as the Outstanding Member of his class of 1939 at Drexel Evening College.

RCA INCREASING OUTPUT OF COLOR TV TUBES BY 50 PERCENT IN 1964

RCA will increase its production of color television picture tubes in 1964 by more than 50 percent over 1963. But it will continue allocating the supply to set manufacturers because output will still fall short of demand.

Douglas Y. Smith, Vice President, RCA Electronic Components and Devices, said the company will produce 1.3 million color tubes in 1964. On this basis, an industry-wide total of 1.7 million is a reasonable expectation for the year. In his opinion, nearly all will be the standard 21-inch round shadow-mask tube. A small number will be rectangular versions, but still employing the RCA three-gun, shadowmask principle.

Mr. Smith disclosed that RCA is developing a new 25-inch, 90-degree rectangular color picture tube. It is expected to go into pilot production during the second quarter of 1964. This tube will employ a new glass bulb especially designed for color requirements. During the second half, the rectangular tube should become available in limited quantities for sampling to set manufacturers.

RCA LABORATORIES HONORS DR. WEIMER

Dr. Paul K. Weimer, of RCA Laboratories, has been named a *Fellow* of the Technical Staff for his continued outstanding technical achievements. (The designation of Fellow was established by RCA Laboratories in early 1959 and is comparable to the same title used by universities and virtually all technical societies.) Dr. Weimer joined RCA Laboratories in 1942, and is well known for his basic contributions to the development of the image orthicon and vidicon, and for recent pioneering in thin-film technology. He developed the first known thin-film transistor in 1961 (see RCA ENGINEER 7-6, April-May 1962). He received the *1963 David Sarnoff Outstanding Achievement Award in Science.*

The recipient of four *RCA Laboratories Achievement Awards,* Dr. Weimer has also been widely honored for his earlier television camera tube research. Among these is the *1959 Vladimir K. Zworykin Television Prize* of the IRE. He holds more than 30 U.S. patents. Dr. Weimer is a *Fellow* of the IEEE and a member of the American Physical Society and Sigma Xi.

BAKER WINS SLOAN FELLOWSHIP

Albert L. Baker of the RCA Service Co., Cherry Hill, N. J., has been awarded an Alfred P. Sloan Fellowship in Executive Development at the M.I.T. School of Industrial Management. He is one of four young business executives to be selected. The Sloan Fellows will move with their families to the Cambridge, Mass., area in June to begin a year of intensive study. Many of the Fellows will complete MIT's requirements for an MS in Industrial Management. Mr. Baker, who is 42, started with RCA in 1959 as Manager, Contract Administration, at the Missile Test Project, Patrick AFB, Fla. He was appointed to his present position, Manager, Contract Development, in 1962. He received a BS in Business Administration from Lehigh University in 1948.

SCIENCE TEACHERS WORKSHOP HELD AT RCA LABS

Science teachers from ten public and private schools in the Princeton area attended a science teachers workshop held at RCA Laboratories on April 22 under the auspices of the Princeton Area Science Education Committee. This year the science workshop theme was "Solid-State Electronics."

Dr. G. Warfield, Electronics Research Laboratory, welcomed the teachers and outlined the day's sessions. **T. O. Stanley,** head of the Integrated Electronics group, began the discussions with a talk on "What Is Electronics?" Dr. Warfield then outlined basic concepts in solid-state electronics, and **J. Olmstead,** of ECD, Somerville, discussed various types of solid-state devices. The materials technology of solid-state electronics was explained by **D. Richman,** Materials Research Laboratory. In the final session, **Dr. J. T. Wallmark,** head of the Solid-State Device Technology group, discussed some of the future directions and applications of integrated electronics. A similar science teachers workshop on "Light—Its Dimensions, Generation, Propagation, and Detection" was held last year at RCA Laboratories under the direction of PASEC.

HAMMERSCHMIDT PRESENTED DISTINGUISHED ALUMNI AWARD

A. L. Hammerschmidt, Chief Engineer, DEP Missile and Surface Radar Division, Moorestown, N. J., has been given a *Distinguished Alumni Award* by The Ohio State University. He was cited "for his eminent achievements in the field of radio and television, his contributions to America's missile and surface radar capability, and his demonstrated ability in translating his research and the work of others into useful engineering systems and stepping-stones for the future."

CORRECTION:

In the April-May 1964 issue, Vol. 9, No. 6, in the presentation of the *1964 David Sarnoff Outstanding Achievement Awards* (pages 44 and 45), two names erroneously appear in large type across the center of the 2-page spread—these are *Dr. Benjamin Abeles, Dr. George D. Cody,* names of men who *did not* receive the award for 1964, but *did* receive the award in a previous year (1963). All other information on pages 44 and 45 about the *1964 Awards* is correct.

. . . PROMOTIONS . . .

to Engineering Leader & Manager

As reported by your Personnel Activity during the past two months. Location and new supervisor appear in parenthesis.

Electronic Data Processing

F. Friedman: from Sr. Mbr.D&D Eng. Staff to *Ldr., Technical Staff* (J. R. Hammond) West Palm Beach

A. T. Ling: from Mgr. Machine Logic Eng. to *Staff Engr.* (A. D. Beard) EDP Engineering, Camden

RCA Communications, Inc.

C. F. Frost: from Mgr., Tech. Training to *Mgr., Tech. Training & Engineering Services*, N. Y.

M. Logiadis: from Design Engr. to *Group Ldr., Station Facilities Equipment & Systems*

E. J. Williamson: from Design Engr. to *Group Ldr., Station Facilities Equipment and Systems*

RCA Service Co.

J. F. Chase: from Mgr., Cape Telemetry to *Mgr., System Project-Telemetry Rehabilitation* (Dr. L. E. Mertens) Florida

C. P. Fort: from Assoc. Engr. to *Ldr., Engrs.* (A. Freeman) Site Engineering, Thule, Greenland

H. B. Hudiburg: from Engr. BMEWS to *Ldr., Engineers-BMEWS* (E. Barratt) BMEWS Site I, Technical Operations

H. Isaacson: from Ldr., Engrs. to *Mgr., Engineering Applications* (C. E. Ettinger) Field Projects—Reliability Facilities

C. E. Perkins: from Mgr., Elex. Sys. Data Red. to *Mgr., Signature Analysis* (C. R. Scott, Data Processing) Cherry Hill

J. W. Stephenson: from Sr. Engr. to *Mgr., Real Time Computations* (J. S. Garrett, Math. Services) Cherry Hill

R. H. Tabeling: from Sr. Engr. to *Mgr., System Project-Range Control Center* (L. E. Mertens, Staff Scientist) Cherry Hill

M. J. Van Brunt: from Mgr., Operations Control to *Mgr., System Project ARIS* (Dr. L. E. Mertens) Florida

C. H. Welch: from Sr. Engr. to *Mgr., System Project-Real Time Computer System* (Dr. L. E. Mertens) Florida

C. V. Williams: from Ldr., Elx. Com. to *Mgr., Math Analysis* (J. R. Garrett, Mathematical Services) Cherry Hill

Astro-Electronics Div.—DEP

H. Hendel: from Sr. Engr. to *Ldr., Engrs.* (E. C. Hutter) Physical Research, Princeton

Aerospace Systems Div.—DEP

S. Steinfeld: from Sr. Mbr. Dev. & Des. Engr. Staff to *Ldr. Dev. & Des. Eng. Staff* (E. Wendkos) Van Nuys

Communications Systems Div.—DEP

O. D. Sebastian: from Ldr., Eng. Projects to *Mgr., Engineering* (I. K. Munson) Production Configuration Control, Cambridge

Electronic Components and Devices

C. W. Bizal: from Mgr., Conversion Tube Dev. Shop to *Mgr., Plant Engineering* (Mgr., Operations Svcs.) Lancaster

R. D. Faulkner: from Sr. Engr., Prod. Dev. to *Mgr., Conversion Tube Dev. Shop* (Mgr., Advanced Dev. Eng.-Conv. Tube) Lancaster

J. Handen: from Engr. Mfg. to *Eng. Ldr., Mfg.* (J. Rivera) Production Eng., Somerville

K. S. Ling: from Sr. Engr. Prod. Dev. to *Mgr., Prod. Eng.* (Mgr., Photocell Oper.) Product Eng. Photocell, Lancaster

J. G. Ottos: from Sr. Engr. to *Eng. Ldr., Spec. Equipment Eng. Section,* Elec. Measurements & Environ. Eng. Lab (J. K. Glover) Lancaster

H. A. Stern: from Engr., Prod. Dev. to *Eng. Ldr., Prod. Dev.* (Mgr., Chemical & Phys. Svcs.-Power Tube & Parts Mfg., Lancaster

STAFF ANNOUNCEMENTS

Product Engineering, Research and Engineering: On May 18, 1964, **Dr. G. D. Gordon** was appoined Administrator, Course Development, for the Current Concepts in Science and Engineering Program (offices in 2-7, Camden). He reports to **J. W. Wentworth,** Manager, Current Concepts in Science and Engineering Program, Product Engineering Professional Development.

DEP Data Systems Center, Bethesda, Md.: Effective, May 6, 1964, **G. A. Peters,** Manager, Data Systems Center, announces his organization as follows: **L. G. Fredette,** Manager, Financial Operations; **G. I. Gaston,** Manager, Marketing; **A. M. Kreger,** Manager, Administrative Services; **P. R. Reimers,** Manager, Information Systems Analysis and Acting Manager, Programming Applied Research; and **B. H. Sams,** Manager, Programming Sciences.

RCA Service Co., Cape Kennedy, Fla.: **Dr. Bernhard E. Keiser,** recently of RCA Laboratories has transferred to RCA Service Company as Staff Scientist for the NASA Base Communications project at Cape Kennedy, Florida. Dr. Keiser, who held a Leader position on RCA Laboratories' PANGLOSS project for a number of years, will report administratively to **Mr. E. Sears,** Manager of the NASA Base Communications project.

Technical Programs, ECD, Somerville: Effective April 1, 1964, **H. V. Knauf** was appointed Manager, Photomask Operation, reporting to **E. O. Johnson,** Manager, Engineering.

ECD Commercial Receiving Tube & Semiconductor Division, Needham, Mass.: Effective April 1, 1964, **A. C. Knowles** was appointed Manager, Applications, Memory Products, reporting to **F. E. Vinal,** Manager, Memory Products Engineering, Memory Products Operations Dept.

ECD Commercial Receiving Tube and Semiconductor Division, Somerville and Harrison: On April 1, 1964, **E. Rudolph** was appointed Manager, Equipment Design and Development, reporting to **N. H. Green,** Manager, Commercial Receiving Tube and Semiconductor Operations Department. Mr. Rudolph's staff is: **M. M. Bell,** Manager, Mechanical/Electrical Design—Somerville; **E. Rudolph,** Acting Manager, Special Equipment Development Projects and Receiving Tube Equipment Development Design; **R. J. Hanlon,** Manager, Equipment Development Shop—Harrison; **H. S. Hull,** Manager, Equipment Development Shop—Somerville; **G. A. Santulli,** Manager, Technical Services—Somerville; **E. Rudolph,** Acting Manager, Technical Services—Harrison; and **H. Hermanny,** Manager, Equipment Development Resident Engineering.

ECD Industrial Tube and Semiconductor Division, Harrison: Effective April 1, 1964, **H. K. Jenny,** Manager, Microwave Engineering, Microwave Tube Operations Dept., announces his organization as: **W. J. Dodds,** Manager, Solid-State Device and Pencil Tube Engineering; **M. Nowogrodzki,** Manager, Microwave Engineering Programs; **F. Sterzer,** Manager, Microwave Applied Research; **R. G. Talpey,** Manager, Microwave Support Engineering; and **F. E. Vaccaro,** Manager, Traveling-Wave Tube Engineering.

ERDMAN NAMED V.P. OF CORPORATE "NEW BUSINESS PROGRAMS" ACTIVITY

On May 1, 1964, **F. H. Erdman** was appointed Division Vice President, New Business Programs, reporting to **Dr. Elmer W. Engstrom,** President RCA. In this capacity, Mr. Erdman will be responsible for implementing, as directed, new business programs which do not normally fall within the scope of an existing product division or subsidiary company. In addition, Mr. Erdman will coordinate projects of corporate-wide interest. Mr. Erdman will continue the responsibilities that he has held for the Industrial and Automation Products activity.

RETTINGER HEADS NEW BCP-BURBANK ACOUSTICAL CONSULTING SERVICE

A new acoustical consulting service, under the direction of **Michael Rettinger** as engineer in charge, was announced today by the Burbank, California, facility of the Broadcast and Communications Products Division. The consulting service, previously available only to users of RCA film recording equipment, is being extended to include architects, builders and others requiring professional counsel in acoustics.

ROUDAKOFF AND RAPPAPORT ASSIGNED ADDITIONAL DUTIES IN DIRECT ENERGY CONVERSION

Assignment of **Paul P. Roudakoff** and **Paul Rappaport** to expanded duties in support of growing projects in the field of direct energy conversion was announced on April 21, 1964 by **L. R. Day,** General Manager, Special Electronic Components Division, EC&D. Mr. Roudakoff, previously Project Manager, Thermoelectric Materials and Devices, has been named Manager, Marketing Development, Direct Energy Conversion Department. He will be responsible for directing sales and marketing of thermoelectric devices, thermionic energy converters, solar cells, superconductor materials and devices. Mr. Rappaport will become a special advisor to Mr. Day on coordination of all aspects of RCA's technical efforts concerning direct energy conversion. He also will continue to head the direct energy conversion research group at the RCA Laboratories, Princeton; he has held this position since 1960.

Headquarters of the RCA Special Electronic Components Division is at Harrison, N. J., where work on thermoelectrics is located. Other direct energy conversion projects are conducted at RCA plants in Lancaster and Mountaintop, Pa., as well as Somerville and Princeton, N. J. (**Editor's note:** *The Oct.-Nov. 1963* RCA ENGINEER, *Vol. 9, No. 3, featured 12 papers on direct energy conversion.*)

CORRECTION

In the April-May 1964 issue, Vol. 9, No. 6, in the paper by A. S. Budnick, "Value Engineering or Industrial Engineering?", on Page 7 correct the center column as follows: Line 15 appearing therein should correctly have been line 10, so that it reads: ". . . *manifest the need for an extremely technical staff. Both activities rely on the people responsible* . . ."

FIRST SESSION OF MICROELECTRONICS COURSE DRAWS 350 AT MOORESTOWN

On April 22, 1964, approximately 350 engineers, technicians and supervisors from the Camden, Somerville, and Moorestown plants met at Moorestown for the first session of a new after-hours course on *Microelectronics Design and Application.* Before the first lecture on semiconductor theory and technology by **I. Kalish** of the Defense Microelectronics (DME) activity at Somerville, **F. W. Anderson** stated that this was the *most important after-hours course ever presented by RCA.*

The introduction to the microelectronics course was made by **C. Dunaief** of DME. Mr. Dunaief has been responsible for securing and coordinating the speakers from the Somerville Plant and will himself deliver one of the lectures.

The entire course was established by **R. Taynton,** M&SR Coordinator for Microelectronics, and **W. M. Swartley** of Moorestown Personnel Training and consists of nine Wednesday evening sessions from 5:30 to 7:30, with subsequent meetings to be held in the Moorestown Junior High School —*R. W. Bugglin*

600 ATTEND SEMINAR CONDUCTED BY ECD ENGINEERS ON SOLID-STATE-DEVICE APPLICATIONS

Engineers from the EC&D semiconductor activities at Somerville, Needham, and Mountaintop presented a series of papers to more than 600 design engineers from industry and government at an RCA-sponsored "Solid-State Device Applications Seminar" at the Statler Hilton Hotel, New York City, April 16, 1964. **E. O. Johnson,** Manager, Engineering, Technical Programs, ECD, presided.

Eleven papers by RCA engineers were delivered at the morning and afternoon sessions of the all-day seminar, as follows:

- "Power-Transistors for Audio-Frequency Applications," **H. M. Kleinman**
- "Transistor Circuit Design for 450 Mc and Above," **P. E. Kolk**
- "Design of Large-Signal VHF Transistor Power Amplifiers," **R. Minton**
- "Current Considerations for Silicon-Controlled-Rectifier Circuits," **D. E. Burke**
- "High-Speed Power-Switching Applications," **R. L. Wilson**
- "Design of Microwave Power Sources Using Varactors," **A. H. Solomon**
- "The MOS Field-Effect Transistor," **D. M. Griswold**
- "Wide-Operating-Range Computer Switching Transistors," **A. J. Bosso**
- "Microferrite Memories," **L. A. Wood**
- "Wide-Temperature Cores," **H. P. Lemaire**
- "High-Speed Magnetic Memory Systems and Their Applications," **B. P. Kane**

For information on any of these papers, contact Commercial Engineering, ECD, Harrison, N. J.

BROWN AND LAPORT VISIT 3,060-MILE CENTO MICROWAVE PROJECT

Dr. George H. Brown, Vice President, Research and Engineering, and **Edmund A. Laport,** Director, Communications Engineering, Princeton, made a consulting tour during March and April of portions of the RCA microwave project for the Central Treaty Organization (CENTO). This 600-channel, MM-600 2-Gc system spans a route distance of 3,060 miles from Ankara, Turkey to Karachi, Pakistan, via Tehran and Ispahan, Iran.

FILM AVAILABLE ON CW-60 MICROWAVE EQUIPMENT

The design techniques used for RCA's CW-60 microwave equipment are shown in a new 16mm color motion picture available from the Broadcast and Communications Products Division. Entitled "The RCA Solid-State CW-60 Microwave," it includes scenes of the equipment's first field installation and animated diagrams to explain the solid-state power generation and switching circuits. (The CW-60 prototype unit is now in its third year of operation without maintenance.) Prints of the film will be loaned to communications engineers and to other technically oriented groups. *Contact F. H. Weikel, Bldg. 15-5, Camden.*

WIRE-WRAP PRODUCTION CENTER ESTABLISHED IN CSD, CAMBRIDGE

An *Automatic Wire-Wrap Production Center* has been established in the DEP Communications Systems Division plant in Cambridge, Ohio. The facility is the first of its kind in RCA. It provides a high degree of mechanization in the making of low cost, highly reliable electrical connections.

The Automatic Wire-Wrap Production Center has a Gardner-Denver machine and associated punched card equipments. The machine can be programmed to wire any size panel up to 22 by 42 inches or groups of smaller panels palleted together to the same total dimensions. Wire sizes from 22 AWG to 30 AWG can be employed.

Cambridge Product Engineering has prepared a report entitled *Design Guide for Automatic Wire-Wrap,* aimed at engineers developing equipments that utilize the advantages of the automatic wire-wrap system. Also, a 3-minute, sound, black-and-white film depicting the operation of this machine is available. Contact **C. R. Doughten** (PC-5942), Building 10-4-4, Camden.

DEP Central Engineering, Camden, has assisted CSD in the development of wire-wrap techniques and support documentation. RCA Drawing No. 8533200, titled *Solderless Wrap Connections,* lists the applicable Manufacturing Specifications, Workmanship Standards, and Purchase Specifications relating to approved tools, wires, and connector configuration. These documents provide engineering and manufacturing controls for the automatic wrapping machine, as well as hand tools. For information on these documents, call **N. B. Shain,** PC-3447, Bldg. 1-6-5.

INDUCTIVE COMPONENT AND POWER SUPPLY ENGINEERING ACTIVITIES OFFER SERVICES TO RCA

The Inductive Component and Power Supply Engineering Activity of the DEP Communications Systems Division is now located in Buildings 1 and 13 under the responsibility of **A. Fogel.** Coil Engineering, as well as the Coil Model Shop, is located in Building 1-6. The transformer engineering labs are located in Building 1-2, with factory production performed in Building 1-2 and Model Shop production in Building 1-1. The Power Supply Engineering Laboratories are located in Building 13-7, with production in either the factory or Model Shops.

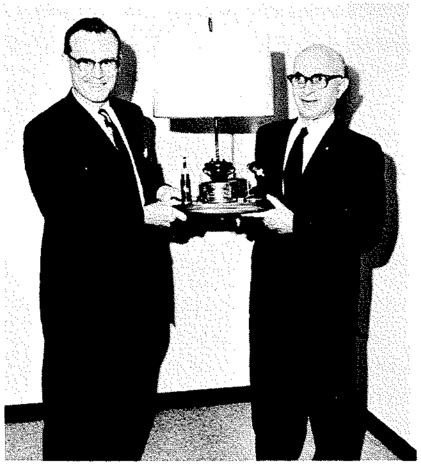
The Inductive Component Engineering and product line development is one of the oldest in the RCA facilities, having a continuous work charter from the inception of RCA. The present group of engineers, representing close to 100 man-years of transformer design experience, design all types of power, current-limiting, input, output, impedance matching, pulse, modulation, converter and inverter transformers, in addition to filter, Hi-Q, swinging and saturable inductors from less than 1-mw to 10-kva capacity, both for commercial and military application. The RF coil services available are capable of providing a variety of different inductive elements up to 200-Mc operating frequency and including such types as IF, RF conductors, passive filters, delay lines, broadband transformers, tuning assemblies, and functional stage assemblies applicable to both military and industrial product line and production.

The Power Supply Engineering Activity has been in existence for the last several years and has designed a wide variety of power supplies. Advanced state-of-the-art developments are also being pursued in this activity. Present investigations are being made of DC-to-DC converters operating up to 50 kc.

The services of these activities are available to both RCA defense and commercial divisions. The activity welcomes the opportunity to quote on any requirements on a competitive basis.—*J. T. Molieri, Mgr. Design Assurance Engineering and Controls*

FIVE RCA ENGINEERS HONORED BY IEEE

Five RCA engineers were among the Past Chairman honored by the IEEE Philadelphia Section at its annual "Past Chairmen's Night," Mar. 9, 1964 at the Engineer's Club, Philadelphia. They are: left to right, A. N. Curtiss, RCA Laboratories, Princeton, N.J.; Dr. H. J. Woll, DEP Aerospace Systems Division, Burlington, Mass.; C. M. Burrill, DEP Astro-Electronics Division, Princeton, N.J.; T. H. Story, DEP Communications Systems Division, Camden; and M. S. Corrington, DEP Applied Research, Camden.



E. D. Becken (l.) presents D. S. Rau with a lamp (designed by R. K. Andres of RCA Communications, Inc.) which is made from components symbolizing his career in communications.

BECKEN AND KIRKWOOD NAMED TO RCA ENGINEER ADVISORY BOARD

E. D. Becken, Vice President and Chief Engineer, RCA Communications, Inc., New York City, has been named to the RCA ENGINEER Advisory Board. He replaces **D. S. Rau,** formerly Vice President, Engineering, who has retired.

L. R. Kirkwood, Chief Engineer, RCA Victor Home Instruments Division, Indianapolis, Indiana, has been named to the RCA ENGINEER Advisory Board. Mr. Kirkwood replaces **E. I. Anderson** who is now Manager, Operations, for that Division.

Eugene D. Becken received his BSEE from the University of North Dakota in 1932 and the MSEE from the University of Minnesota in 1933. He has been with RCA Communications, Inc., since 1935. He was awarded a Sloan Fellowship at MIT in 1951 which led to an MS in Business and Engineering Administration. In his present position, he is responsible for communication equipment and system design and development, and for the technical operation and maintenance of the Company's worldwide international communication services. Mr. Becken is a registered Professional Engineer in New York State and a member of the IEEE, Sigma Tau, and Sigma Xi.

Loren R. Kirkwood received his BSEE from Kansas State University. He joined RCA in 1930, and through 1941 made important contributions to radio and early high-fidelity. Between 1941 and 1946, he engaged in engineering of communications equipment for the military. From 1946 to 1950, he developed one of the first AC-DC, AM-FM home radios, and contributing to the 45-rpm record player. Between 1950 and 1959, he directed receiver activities and development for all RCA color television demonstrations and field tests. In 1951, he received the *RCA Award of Merit* for his work in color TV. Between 1959 and 1963, he was Manager of TV Product Engineering. In 1963, he was named Chief Engineer of RCA Victor Home Instruments. He is a Fellow of the IEEE.

L. R. Kirkwood

D. S. RAU RETIRES

David S. Rau, who was Vice President, Engineering, for RCA Communications, Inc., retired recently, culminating a distinguished engineering and management career with RCA. Mr. Rau was a long-time member of the RCA ENGINEER Advisory Board whose respected technical and editorial judgment has been a most significant factor in the development of the journal.

Mr. Rau's early responsibilities included engineering a nation-wide domestic HF radiotelegraph system supplemented by RCA's first VHF system between New York City and Philadelphia, and its first UHF circuits for keying control of transmitting stations. He then assumed engineering-management duties in RCA Communications, Inc., advancing to Vice President and Chief Engineer, and then to Vice President, Engineering. His activities in IEEE included membership on many committees, and he was named a *Fellow* of IEEE in 1960.

I. N. BROWN COORDINATES PAPERS AND REPORTS FOR DEP-SEER

On Page 85 of the last issue, (April-May 1964), a listing was presented of those in DEP who assist **F. D. Whitmore** in the administration of technical papers and RCA Technical Reports (TR's) and Engineering Memoranda (EM's). To that list should be added **I. N. Brown,** who assists Mr. Whitmore in handling of papers, TR's, and EM's originating in the DEP Systems Engineering, Evaluation, and Research (SEER) activity, located in Moorestown, N.J.

HAVE YOU WRITTEN A BOOK?

The RCA ENGINEER plans to give special recognition for the publication of technical and business books by RCA authors. *If you have published a book since 1/1/63,* or know of one, send the following to your Editorial Representative or directly to the Editorial Office (2-8, Camden): *author(s), title, publisher, date,* and *price;* and a *short summary* of the content (about 100 words).

MOORESTOWN HOLDS ENGINEERING SYMPOSIUM ON MICROELECTRONICS

A four-hour symposium held in the Moorestown plant auditorium on March 13th, acquainted engineers with the RCA and divisional efforts in the microelectronics field. Attended by 250 engineers from both AADS-70 and M&SR divisions, the material presented was tutorial in nature and designed to introduce the engineers to microelectronics with emphasis on integrated circuits. Types of microelements were defined and methods of manufacture were related to inherent cost, size, reliability, and electrical characteristics.

Following introductions and announcements by divisional chief engineers, **A. L. Hammerschmidt** and **R. A. Newell,** presentations were made by Somerville personnel, **R. Aires, C. Dunaief,** and **M. Malchow.** Additional speakers included **D. Schnorr** from Central Engineering, **A. Levy** and **H. Eigner** from AADS-70, and **H. Rouland** and **J. A. Bauer** from M&SR. A panel consisting of **H. Rouland, J. A. Bauer, W. Blumenstein,** and **R. Taynton** of Moorestown, **E. A. Szulkalski** of Central Engineering, and **R. Aires** discussed a variety of design and application aspects of microelectronics.—*T. Greene*

PROFESSIONAL ACTIVITIES

DEP-AED, Princeton, N.J.: **Sam Rhodeside** was re-elected to the AIAA Technical Committee on Materials for the second consecutive year.—*J. C. Phillips.*

RCA Victor Co. Ltd., Montreal: **Dr. F. G. R. Warren,** Systems Laboratory Director, Research Laboratories, was recently elected to a 3-year term on the Administrative Committee of the IEEE Professional Technical Group on Microwave Theory and Techniques.—*H. J. Russell.*

ECD, Lancaster, Pa.: **L. D. Miller,** Conversion Tube Advanced Development, attended the IRIS Symposium held April 1, 1964, at RCA Burlington, Mass. The following engineers from the Conversion Tube Photo and Image Operation attended the Ninth Scintillation and Semiconductor Counter Symposium, held in Washington, D.C., on February 26, 27, and 28: **H. R. Krall, J. P. Sverha, R. O. Deneen, A. F. McDonie, W. Widmaier, A. G. Nekut, G. Butterwick, W. K. Peifer, A. L. Morehead.** —*R. Kauffman.*

DEP-CSD Systems Lab., N.Y.: **Berthold Sheffield** was the guest speaker at the RCA Institutes graduation exercises held on February 26, 1964 at the School of Education Auditorium at N.Y. University. His address is being published in the RCA Institutes newspaper *Current Lines* and in the Eta Kappa Nu *The Bridge.* Mr. Sheffield is President of the New York Alumni Chapter of Eta Kappa Nu.—*M. Rosenthal.*

DEP-CSD, Camden: **R. E. Bailey** was elected Treasurer of the combined groups on Communications Systems, Vehicular Communications, and the Communications Technical Division of the Philadelphia Section, IEEE. **D. R. Marsh** and **W. R. McLaughlin** were elected to the combined-group executive committee.

Broadcast and Communications Products Division, Camden: **M. K. Wilder** was elected Vice Chairman of the combined groups on Communications Systems, Vehicular Communications, and the Communications Technical Division of the Philadelphia Section, IEEE.

RCA ENGINEER BINDERS AVAILABLE

Wire-rod-type, brown, simulated-leather binders are available for binding back issues of the RCA ENGINEER. The binders are 9¼ x 12 x 3¼, and will hold about 10 issues each. (Six binders will house all issues since Vol. 1, No. 1). RCA ENGINEER copies (or similar size magazines) are held in place by wire rods (supplied) that run along the center fold of the magazine and snap in place (no need to punch holes or otherwise mutilate the issue). These binders may be ordered directly for two-week delivery as follows: Order by stock number and description *exactly as below;* make check or money order payable *directly to the vendor,* and specify method of shipment:

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