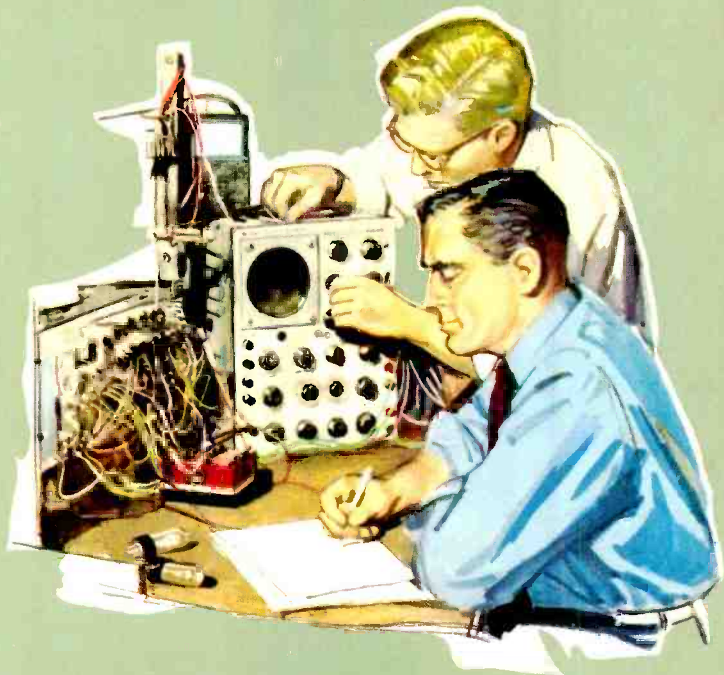
10th
ANNIVERSARY ISSUE



RCA ENGINEER

Vol. 11 — No. 1
JUNE-JULY, 1965

OUR COVER

As has been our custom over the past ten years in every June-July issue, our cover for this tenth-anniversary issue repeats the basic cover design of the first issue of the RCA ENGINEER (June-July) 1955, Vol. 1, No. 1). Cover art direction, J. Parvin.

A Tenth Anniversary

During the past decade, more than 3,800 printed pages in 60 issues of the RCA ENGINEER reflect RCA's continuing technological advancement. More than 2,000 authors have documented such progress by their contributions to the RCA ENGINEER —from early papers such as "The BIZMAC Electronic Accounting System," "Color Television," and "Experimental High-Frequency Transistors,"—to current papers on "Monolithic Silicon Integrated Circuits," "Advanced Space Electronic Systems," and "Life Sciences," to name a few. Future issues will discuss "Plasmas," "Automata," "Environmental Sciences," "Advanced Computer Applications," and other important technical progress.

Each of us on a personal basis witnesses marked technological changes in those areas most familiar to us; but, *do we have the adaptive ability to keep our associates informed at a pace commensurate with that of innovation itself? What is your professional contribution of valuable information to other engineering groups within RCA?*

Fortunately, engineers are intensively involved in searching for more and more technical knowledge. They anticipate greater challenges; and, quite naturally, they are concerned with the nature and the degree of recognition of their professional technical work and that of the entire company. Fortunately also, RCA engineers and scientists can fulfill this need to keep associates informed through publication of professional papers in the RCA ENGINEER, the *RCA Review*, and by disseminating technical reports within RCA. Further, the total image of RCA's technical competence is enhanced and recognized by the contributions of our engineers and scientists to outside professional journals and societies.

Thus, each engineer's professional success, RCA's technological progress, and RCA's business success are all strongly influenced by how well each engineer generates, publishes, and uses significant technical information.

D F Schmit

D. F. Schmit
Staff Vice President,
Product Engineering;
Research and Engineering

RCA ENGINEER

VOL. 11, NO. 1
JUNE-JULY 1965

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PAPERS

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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.

The Engineer and the Corporation

RCA TECHNICAL PAPERS AND THEIR APPROVAL

W. O. HADLOCK, Mgr.*
RCA Staff Technical Publications
Product Engineering, Research and Engineering
Camden, N. J.

The RCA technical staff annually writes more than 1.200 technical papers and abstracts for publication and presentation—a most impressive writing effort. But, it is not just the quantity of papers that is important; rather, it is their quality and their contribution to the professional stature of the author and to RCA's technical reputation.

Prior to publication or presentation, RCA makes certain that each of these papers is of the highest possible caliber. RCA assures also that each paper conforms with important policy, patent, legal, security, and commercial requirements—and is generally presented in the best interests of the company. Therefore, *all* technical papers are appropriately reviewed and approved at RCA before being submitted to a professional society or journal.

RCA POLICY CONCERNING TECHNICAL PAPERS

RCA's long-standing corporate policy strongly encourages the preparation and publication of papers by its engineers and scientists. This is clearly stated in the official corporate policy instruction[1] as follows:

> "The Radio Corporation of America encourages the writing of papers by qualified personnel for publication and presentation. Such papers help establish the author in his profession and contribute to the good will of the public toward RCA. It is important that such papers be timely, well written, sound from a technical point of view, and that they conform with all company policies."

Each RCA major operating unit has a specific "Procedure Instruction" embodying such policies and governing the review and approval cycle for technical papers.

TECHNICAL PUBLICATIONS ADMINISTRATORS

To implement approvals, each major operating unit in RCA has a Technical Publications Administrator representing the Chief Engineer to coordinate all approval matters (see Table I). These men answer questions and interpret policy, and in some areas, assist the author in getting a paper published once it is approved.

The engineer-author should look to his Techical Publications Administrator for assistance not only in perfecting, but also in expediting his paper through the review and approval cycle. The time required to complete this cycle varies between divisions and depends upon the number and type of reviews required.

Final manuscript received April 1, 1965
* Mr. Hadlock is also Editor, RCA ENGINEER

TABLE I—Technical Publications Administrators and TR and EM Coordinators

ADMINISTRATOR	DIVISION AND LOCATION
Division Technical Publications Administrators:	
K. A. Chittick .... 317—636-5311 (VH-2523)	RCA Victor Home Instruments Division, 600 North Sherman Dr., Indianapolis, Ind.
C. Frost .... 212—363-2121 (4070)	RCA Communications, Inc., 66 Broad St., New York, N. Y.
M. G. Gander .... 609—963-8000 (PY-5687)	RCA Service Company, Bldg. 203-3, Cherry Hill, N. J.
W. A. Howard .... 212—247-8300 (4385)	National Broadcasting Company, Inc., 30 Rockefeller Plaza, New York, N. Y.
W. A. Howard .... 212—247-8300 (4385)	RCA Institutes, Inc., 30 Rockefeller Plaza, New York, N. Y.
A. M. Max .... 317—636-5311 (VM-519)	RCA Victor Record Division, 501 N. LaSalle Street, Indianapolis, Ind.
C. A. Meyer .... 609—485-3900 (TH-2216)	RCA Electronic Components and Devices, 415 S. 5th Street, Harrison, N. J.
D. R. Pratt .... 609—963-8000 (PC-4438)	Broadcast and Communications Products Div., Bldg. 13-4, Camden 2, N. J.
H. J. Russell .... 514—Wellington 3-7551 (452)	RCA Victor Company, Ltd., 1001 Lenoir Street, Montreal, Canada
C. W. Sall .... 609—452-2700 (2321)	RCA Laboratories, Princeton, N. J.
L. A. Shotliff .... 212—689-7200 (RC-225)	RCA International Division, 30 Rockefeller Plaza, New York, N. Y.
H. H. Spencer .... 609—963-8000 (PC-4411)	RCA Electronic Data Processing, Bldg. 10-2, Camden 2, N. J.
F. D. Whitmore .... 609—963-8000 (PC-2595)	Defense Electronic Products, Bldg. 1-6, Camden 2, N. J.
Assisting Mr. Whitmore in DEP are the following—some men handling papers only, reports only, or both reports and papers:	
E. Williams .... 272—1500 (3063) (Papers, and TR's and EM's)	Aerospace Systems Division, Routes 62 and 3, Burlington, Mass.
S. Hersh .... 364—8111 (3315) (Papers, and TR's and EM's)	Aerospace Systems Division, 8500 Balboa Blvd., Van Nuys, Calif.
C. W. Fields .... 609—963-8000 (PC-4468) (Papers, and TR's and EM's)	Communications Systems Division, Bldg. 10-4, Camden 2, N. J.
T. Greene .... 609—963-8000 (PM-4532) (Papers only)	Missile and Surface Radar Division, Bldg. 108-113, Moorestown, N. J.
Mrs. C. Wing .... 609—963-8000 (PM-2611) (TR's and EM's only)	Missile and Surface Radar Division, Bldg. 127-228, Moorestown, N. J.
M. Pietz .... 609—963-8000 (PC-5857) (Papers, and TR's and EM's)	Applied Research, Bldg. 10-8, Camden 2, N. J.
J. Lamb .... 609—963-8000 (PC-5294) (Papers only)	Central Engineering, Bldg. 1-6, Camden 2, N. J.
O. A. Cerami .... 609—963-8000 (PC-5576) (TR's and EM's only)	Central Engineering, Bldg. 1-6, Camden 2, N. J.
J. Phillips .... 609—448-3400 (7243) (Papers, and TR's and EM's)	Astro-Electronics Division, Princeton, N. J.
R. Shively .... 609—963-8000 (PM-2868) (Papers, and TR's and EM's)	Systems Eng., Evaluation, and Research, Bldg. 127-310, Moorestown, N. J.
Staff Coordination:	
W. O. Hadlock .... Manager, RCA Staff Technical Publications 609—963-8000 (PC-4018)	Product Engineering, Research & Eng., Bldg. 2-8, Camden 2, N. J.
E. R. Jennings .... Administrator, RCA Staff Technical Publications 609—963-8000 (PC-4018)	Product Engineering, Research & Eng., Bldg. 2-8, Camden 2, N. J.

PUBLISHED PAPERS ARE VALUABLE TO YOU AND RCA

Published papers by qualified RCA engineers and scientists are highly valuable assets; such papers display specific areas of RCA's technical competence and do so in an efficient. unobtrusive and businesslike manner. Equally important. the presentation and publication of papers provide members of the RCA technical staff with a means for professional recognition of their work and identify them with the Corporation and with their specialized field of work.

WHERE TO PUBLISH

There are scores of technical journals and professional technical society meetings that can make good use of RCA authored papers and presentations. Your Technical Publications Administrators (TPA's) have copies of the *RCA Technical Papers Guide* which includes information on more than 200 such journals. Also, your TPA can provide information concerning the meetings and publications of all the major technical professional societies. Each issue of the RCA ENGINEER contains a list of meetings (see "Dates and Deadlines") and a subject-author index to recent publications and presentations by RCA engineers (see "Pen and Podium").

Matching the content of the paper to the interests of the intended reader is an important factor affecting successful placement of papers. This match is accomplished by understanding the editorial requirements of the various journals and the type audiences they tend to reach. (For an excellent discussion of effective papers placement, see Ref. 2.)

Your TPA can provide and discuss with you a selected list of publications available in a given field. Study these publications at your nearest RCA technical library to learn the writing approaches, styles, and formats used.

SOME QUESTIONS AND ANSWERS

Once you have decided upon the writing approach and the content of your paper, the outline and summary can be completed without difficulty. When the paper is written and approved by your engineering manager, you will be ready to submit copies to the TPA for formal review and approval.

As is true with any formal procedure, you may wish to ask questions concerning RCA's system for review and approval of papers, such as additional information concerning governmental approval, handling of abstracts, relation of papers to technical reports (TR's and EM's), handling of books, theses, and abstracts and summaries. Therefore, in an effort to assist the engineer-author, this article attempts to explain the procedure to follow and answer typical questions that commonly arise.

QUESTION: *Is compliance with the approval system requirements necessary?*

ANSWER: It is mandatory. The information in a published paper is public property. Papers describing RCA technical processes, products, methods, etc. must contribute to the overall corporate welfare—not just to the interests of one author, one group, or one Division.

QUESTION: *How many papers are approved each year by RCA? Are many disapproved?*

ANSWER: Some 1,200 full papers and abstracts are reviewed and approved each year. Very few are disapproved in the corporate system, since the initial planning and review in the author's division tends to filter out problem papers before they enter the corporate review. The few that are disapproved are almost always for commercial or patent reasons, government security, or company-policy considerations. If revisions are required, the purpose is usually to protect the commercial interest of other divisions, or to improve the technical content or clarity of the material.

QUESTION: *What approval should be sought before starting a paper?*

ANSWER: No approval in a formal sense, but the author should obtain an endorsement of the writing project from his immediate supervisor who, later on, will be the first step in review and approval of the finished paper—before it enters the corporate approval system.

QUESTION: *May a paper be written on company time?*

ANSWER: This is a matter for the author to work out with his supervisor. The corporate policy specifically encourages writing of papers, and managers may make time available. But their judgment on whether it is practical to use company time is the ruling criterion. This consideration is strong reason for an engineer, when planning the writing of a paper, to start off with a discussion with his immediate supervisor.

QUESTION: *Must the draft of the paper submitted for approval be a finished product, or can it be rough or preliminary?*

ANSWER: The version actually delivered to the TPA for approval processing should be as final as possible, carefully edited, and neatly typed. It should also have at least rough sketches of any illustrations that will be used. Such factors have a definite effect on the reviewers who are judging the suitability and quality of the author's work.

QUESTION: *How many copies of the manuscript are needed for the approval system?*

ANSWER: It varies from six to a dozen or more. Check the local Procedure or the local TPA.

QUESTION: *How much time is needed to gain corporate approval?*

ANSWER: Two to four weeks is usually plenty. How-

WILLIAM O. HADLOCK graduated from Clarkson College of Technology with a BSEE in 1934, and then joined General Electric's Radio Receiver Engineering, where he worked in components engineering, design of farm radios, and later in television transmitter design. During World War II he became Assistant Mgr. of Commercial Service Activities, GE Electronic Tube Division, and introduced GE's series of Electronic Tube Manuals. Mr. Hadlock joined RCA in 1947 to work on the Advertising and Promotion of RCA technical equipment for sale to TV and Broadcast Stations. In 1949, he became Manager, Broadcast Advertising and Sales Promotion, and Managing Editor of "Broadcast News." In 1955, Mr. Hadlock became Editor, "RCA ENGINEER," to inaugurate and publish the present company-wide journal. In 1959, he was also named RCA Staff Technical Publications Administrator for the coordination and approval of RCA technical papers for presentation and publication—and dissemination of TR's and EM's. In 1965 he was named Manager, RCA Staff Technical Publications in which position he also continues as Editor RCA ENGINEER. Mr. Hadlock is a Senior Member of IEEE, Member of the IEEE G-EWS, and a Member of the American Association of Industrial Editors.

ever, if government approval is also required, much more time is ordinarily needed (it can be two or three months and more). It is always best to contact the TPA for lead time.

Question: *Who actually reviews papers for corporate approval?*

Answer: The originating TPA decides where the paper should be sent for review. It will generally include patent, legal, and corporate policy reviews, plus a review by any other Division whose technical or commercial interests are related to or may be affected by the topic of the paper.

Question: *Can the Editorial Representative answer for the TPA on policy matters? Exactly what is the relation of the TPA and the Ed Rep?*

Answer: The TPA provides all answers on divisional policy concerning approval of papers. Editorial Representatives are basically appointed to work on the RCA Engineer, while the TPA is concerned with all RCA technical papers. The TPA always retains responsibility for the proper functioning of the approval system in his area. The Editorial Representative should discuss all approval matters with his TPA to determine local requirements.

Abstracts and Summaries

Question: *May an abstract, outline, or summary of a paper be sent outside of RCA for consideration (for example, to a journal) without going through the approval cycle?*

Answer: No. In fact, most professional societies and journals insist that all company and government clearances be in order before the author submits even an abstract. This fact re-emphasizes that the author must allow sufficient time to secure the required approvals in advance of journal or society deadlines for the initial abstracts.

Question: *Does approval of a summary or outline suffice for approval of the complete paper for publication?*

Answer: No. The complete manuscript must always be submitted for approval before publication.

Question: *Under what circumstances should an abstract be circulated for approval before the paper itself is submitted?*

Answer: For many technical meetings, it is necessary to submit a summary or abstract several months in advance. Occasionally, an engineer may wish to obtain sanction for a proposed paper by submitting a summary for approval before proceeding with the effort of writing the complete paper.

Question: *If an abstract or summary has been approved for a verbal presentation (not to appear in print), must the complete text of the presentation still be approved?*

Answer: Under normal circumstances a complete text or detailed outline should be circulated for approval. Exceptions to this would require special approval; consult your TPA.

Question: *Must brief material, such as book reviews or "Letters to the Editor" of a journal be approved?*

Answer: Yes. Any material destined for publication or presentation that will be identified as being written by an RCA scientist, engineer, or manager, or which concerns work carried on at RCA, must be formally reviewed and approved.

Books, Theses, Etc.

Question: *Must technical books or chapters being contributed to books be approved in the same manner as papers?*

Answer: Yes. If an author plans an entire book, he should submit an outline of it along with a statement of publication plans to his TPA. The TPA can then advise on how to physically handle review of the whole manuscript, since it may be very bulky. This review must be completed before anything is submitted to a publisher, and especially before a contract is made with the publisher of the book. If the author is contributing a chapter to a text, the same procedure applies.

Question: *Must a thesis to be submitted as part of scholastic work be approved?*

Answer: Yes, if the thesis work was done at RCA or is related to any RCA interests. These are considered published literature, since they do become available in the University library. In all cases of thesis writing, the TPA should be consulted for instructions.

Question: *Must nontechnical articles or fiction written by an RCA author be approved?*

Answer: Generally no. However, an article dealing, for example, with a business topic will require divisional and/or corporate approval if it discusses matters pertinent to RCA (accounting practices, operating statistics, personnel management techniques, etc.), especially if the author's affiliation with RCA would be evident in the published writing. Here, again, questions on approvals should be checked with the TPA.

Question: *Are reports for customers, press releases, marketing brochures, or internal company reports (TR's and EM's) handled in the same approval system as technical reports?*

Answer: No. Consult the TPA in any cases of doubt as to proper procedure.

Relation of Papers and TR's, EM's

Question: *Can a paper contain any proprietary information?*

Answer: No. In writing a paper, an author should find out ahead of time as much as possible about what part of the work to be described is proprietary, and what is releasable. Again, this is where planning the paper by discussion with local management can help in avoiding false starts or wasted writing effort.

Question: *Should a paper first be issued as an RCA internal Technical Report or Engineering Memorandum before it can be approved for outside publication?*

Answer: This is up to the originating Division. In the RCA Laboratories, for example, virtually all papers destined for outside publication must first be issued as a Princeton TR. In most product divisions, this decision will be up to the author and his manager.

QUESTION: *Can an RCA internal Technical Report or Engineering Memorandum be adopted and modified for release as a paper for publication?*

ANSWER: Yes, after two conditions are fulfilled: 1) proprietary information is removed and 2) all references to TR's, EM's or other Company Private documents is deleted. Usually, a better quality technical paper will result if it is written "from scratch," although perhaps based on a TR, since the format for a report is somewhat different from the best writing approach for a paper. Never send a marked-up TR or EM to a journal; rather, always prepare a fresh manuscript.

RCA Engineer Papers

QUESTION: *Must all* RCA ENGINEER *papers, including Engineering and Research Notes, be approved?*

ANSWER: Yes, every RCA ENGINEER paper and all ERN's (notes) must receive full approvals. Technical papers for all other RCA publications require approval also.

QUESTION: *If a paper is approved for the* RCA ENGINEER, *must it be re-approved later if it is to be republished elsewhere—and vice-versa?*

ANSWER: Probably not, but in all cases the author's TPA should be consulted concerning any subsequent publication plans, so that he can both keep his records updated and rule on any need for reapproval. It is always advisable to specify on the approval sheets "for publication in the RCA ENGINEER and other suitable technical journal."

Government Contract Work

QUESTION: *Can a paper contain government-classified information—for example classified SECRET?*

ANSWER: Only for "classified symposia," sponsored and cleared by the government, can classified papers be presented. Such papers must also receive corporate approval, in the sense that the TPA of the originating Division must rule in each case on how the corporate approval is to be granted. The terms of the government contract involved will often spell out the criteria to be met in gaining government permission to present a classified technical paper.

QUESTION: *Must papers based on unclassified government contract work be approved in the RCA corporate system, and/or by the government?*

ANSWER: Yes, by both. RCA approval is required for all papers, contract or no; the government contract may specify the conditions and procedures involved in gaining government clearance for publications of papers dealing with work done under that contract. Check with the local contract administrator and/or with the TPA for details on necessary government approvals.

Foreign Publication

QUESTION: *If a paper is to be presented or published in a foreign country or foreign journal, are any special considerations necessary beyond regular corporate approvals?*

ANSWER: Yes, because of import-export laws on technical information and/or possible special commercial considerations. Required RCA Law Department review will be arranged by the originating TPA. Thus, it is important that the approval forms indicate the destination of the material.

Coauthorship, and Other Companies

QUESTION: *If a paper written by an RCA employee describes work that he did at another company, must it be approved?*

ANSWER: Yes, because the author is now an RCA employee. The author should obtain permission from the other company also. However, for the benefit of the readers (and the reviewers) and to clarify RCA's status, the paper should state clearly where the work was done.

QUESTION: *If an RCA man coauthors a paper with a writer from another company, must such a paper be approved by RCA?*

ANSWER: Yes.

QUESTION: *If two or more RCA men from different Divisions coauthor a paper, how should the approvals be handled?*

ANSWER: The TPA of any one of the Divisions involved should be asked to handle the approval reviews. He will circulate review copies to the TPA's of all the other Divisions concerned.

Comments, Revisions, and Disapprovals

QUESTION: *Must comments obtained during approval reviews be complied with by the author?*

ANSWER: Yes, if the paper is approved with the statement that "approval is contingent" on making such revisions. (The Patent Department often comments in this manner.) In addition, other comments may be designed to improve or clarify the paper. Authors may wish to discuss either type of comment and may do so by making arrangements through the TPA.

QUESTION: *After approval is received on a paper, revisions are made to the text; must the paper be re-approved?*

ANSWER: The TPA of the originating Division must be consulted as to whether re-approval is necessary.

QUESTION: *If a paper is disapproved, can it be resubmitted later?*

ANSWER: Yes, if the author feels that the reasons for disapproval have disappeared with time (e.g., filing of a patent application, lifting of government security, or changes in commercial policy). It may also be resubmitted if changes have been made in the disapproved paper to resolve the difficulties.

BIBLIOGRAPHY

1. *Papers for Publication or Presentation,* RCA Policy Instruction 10211, Nov. 10, 1960. (This is a corporate document; it is implemented within each major operating unit by an *Operating Procedure.* Those involved with technical papers activity should consult, for details, the *Operating Procedure* prepared by their own division.

2. C. A. Meyer, "Effective Placement of Engineering Papers," RCA ENGINEER, Vol. 8, No. 2; August-September 1962, in *The Engineer and the Corporation* series; also presented at the 1962 IRE International Convention, PGEWS Session, New York, March 1962, and published in the *1962 IRE Convention Record* under the title "Placement of Technical Papers for Maximum Effectiveness."

NEW STANDARD ABBREVIATIONS FOR TECHNICAL TERMS

Published here is the new IEEE list of symbols (IEEE Standard No. 260, Jan. 15, 1965). This standard, issued through IEEE, is consistent in nearly all respects with the recommendations of the International Organization for Standardization (ISO) and with the current work of the International Electrotechnical Commission (IEC). Beginning with this issue (Vol. 11, No. 1), the printed pages of the RCA ENGINEER will conform with this new IEEE Standard. To aid in applying these to RCA work, the following recommendations for usage are included, based mainly on the IEEE rules but with explanation added by the RCA ENGINEER editors where appropriate.

1. General Application. The new *IEEE Standard* is recommended for use in RCA technical publications except where customer or government requirements stipulate the use of other standards (for example, a MIL-SPEC for a government contract report, etc.).

In the text, these symbols should be used judiciously, and only when it is reasonably certain that the reader will understand them; otherwise it is better practice to spell out the technical term. Symbols on illustrations should also conform to this *IEEE Standard.* With respect to illustrations, RCA authors must remember that RCA drafting groups are used to following a Corporate standard set of drafting abbreviations (somewhat different from the standard printed herein) when they prepare RCA design drawings. Therefore, authors should specify the enclosed abbreviations to the drafting or illustrating group when arranging for illustrations for papers and reports wherein the text follows this *IEEE Standard.* RCA design drawings should, of course, still follow the *Corporate Drafting Manual, Section 8-42-25.*

2. Scope. The new *IEEE Standard* supersedes the abbreviations for units given in *Standards on Abbreviations of Radio-Electronics Terms, 1951* (51 IRE 21 S1). It also supersedes all abbreviations for units previously given as recommendations for authors in various AIEE, IRE, and IEEE publications.

This *IEEE Standard* covers only units of measure, and does not cover abbreviations for other technical terms that are not actually units of measure (such as UHF for ultra-high frequency) or symbols for physical quantities (such as *I* for current). The editors of the RCA ENGINEER recommend the use of all capital letters (without periods) in manuscripts for terms such as UHF, FM, AM, IF, etc. The same applies for acronyms such as BMEWS and TALOS; most acronyms should *always* be written out the first time they appear in text.

3. Style. With few exceptions, the letters forming the unit abbreviations are taken from the names of the units. They are appropriate for use with texts in different languages; and multiplication and division are indicated in ways that resemble algebraic quantities. Every effort should be made to follow the distinction between upper- and lower-case letters, even if the abbreviation appears in applications where the other lettering is in upper-case style (for example, in titles of manuscripts).

Their form is the same for both singular and plural, and they are not followed by a period. When there is a risk of confusion in using the standard symbols such as "in" for inch and "l" for liter, the name of the unit should be spelled out.

4. Compounding. When a compound unit is formed by *multiplication* of two or more other units, its symbol consists of the symbols for the separate units joined by a raised dot (for example, N•m for newton meter). The dot may be omitted in familiar compounds (such as watthour, Wh), if no confusion would result. When a unit symbol prefix is identical to a unit symbol, special care must be taken. For example, m•N indicates the product of the units *meter* and *newton,* while mN is the symbol for *millinewton.*

Positive and negative exponents may be used with the symbols, but care must be taken in text to avoid confusion with superscripts that indicate footnotes or references.

When a compound unit is formed by division of one unit by another, its symbol consists of the symbols for the separate units either separated by a solidus (for example, m/s for meter per second) or multiplied using negative powers (for example, $m \cdot s^{-1}$ for meter per second). In simple cases use of the solidus is preferred, but in no case should more than one solidus on the same line, or a solidus followed by a product, be included in such a combination unless parentheses are inserted to avoid ambiguity. In complicated cases negative powers are better.

Compound prefixes should not be used; for example, $\mu\mu$ for micromicro. Use instead the prefix p for pico.

The list is intended to be reasonably complete, but could not possibly include all units that might conceivably be used in modern electronic technology. Many compound symbols and many illustrations of the use of the metric prefixes are included. Other combined forms may easily be constructed according to the principles set forth.

5. Terms from Other Fields. Obviously, there are many RCA engineers and scientists whose fields are *not* directly involved with electronics—for example, mechanical engineers. In such cases, some needed terms will not be found in this *IEEE Standard.* In such cases, the author will have to exercise discretion and judgment in the use of abbreviations, and as a practical matter, should refer to other pertinent standards—for example, as might be issued by ASME for mechanical design work. More difficult will be cases where interdisciplinary work is involved—such as in electromechanical devices, spacecraft design, etc. In these cases, situations arise where a term like cycles per second may appear in one report or paper in more than one context. For example, in describing *vibration* (to a mechanical engineer, cps) and describing *electronic frequency* (from this *IEEE Standard,* either c/s, or the newer term, hertz). In cases like this the author must exercise common sense. Consistency in abbreviations—especially within one document—is important, and choices will have to be made based on *reader understanding.* Care in selecting and using abbreviations is equally important to care in writing and editing the text. Thus, an abbreviation list, while important and helpful, is *not* a substitute for care and forethought by the author in utilizing technical terminology.

Prefixes for Metric-System Units

Prefix (Multiple)	Symbol
tera (10^{12})	T
giga (10^{9})	G
mega (10^{6})	M
kilo (10^{3})	k
hecto (10^{2})	h
deka (10)	da
deci (10^{-1})	d
centi (10^{-2})	c
milli (10^{-3})	m
micro (10^{-6})	μ
nano (10^{-9})	n
pico (10^{-12})	p
femto (10^{-15})	f
atto (10^{-18})	a

ampere	A
ampere-hour	Ah
ampere-turn	At
angstrom	Å
atmosphere (normal) 1 atm = 101,325 N/m^2	atm
atmosphere (technical) 1 at = 1 kgf/cm^2	at
atomic mass unit (unified) Defined as 1/12 of the mass of an atom of the ^{12}C nuclide. Use of the old atomic mass unit (amu), defined by reference to oxygen, is deprecated.	u
bar 1 bar = 100,000 N/m^2	bar
barn 1 b = 10^{-28}m^2	b

bel	B
billion electronvolts	—
Deprecated; use instead **gigaelectronvolt (GeV).**	
British thermal unit	Btu
calorie (International Table calorie)	cal_{IT}
1 cal_{IT} = 4.1868 joules. The 9th Conference Generale des Poids et Mesures adopted the **joule (J)** as the unit of heat, avoiding the calorie as far as possible.	
calorie (thermochemical calorie)	cal_{th}
1 cal_{th} = 4.1840 joules. Same note as for International Table calorie.)	
candela	cd
candela per square foot	cd/ft^2
candela per square meter	cd/m^2
The name nit is sometimes used for this unit.	
candle	—
Deprecated; the unit of luminous intensity is now the **candela.**	
centimeter	cm
circular mil	cmil
1 cmil = $(\pi/4) \cdot 10^{-6} in^2$	
coulomb	C
cubic centimeter	cm^3
cubic foot	ft^3
cubic foot per minute	ft^3/min
Although cfm is common, it is not recommended.	
cubic foot per second	ft^3/s
cubic inch	in^3
cubic meter	m^3
cubic meter per second	m^3/s
cubic yard	yd^3
curie	Ci
Unit of activity in radiation dosimetry.	
cycle per second	c/s
IEC recommends the new name **hertz (Hz)** for this unit, and hertz has been adopted by the Conference Generale des Poids et Mesures.	
decibel	dB
decibel referred to one milliwatt	dBm
degree (plane angle)	°
degree Celsius	°C
The word centigrade (for the Celsius temperature scale) was abandoned by the Conference Generale des Poids et Mesures in 1948.	
degree Fahrenheit	°F
degree Kelvin	°K
degree (temperature interval or difference on the Kelvin and Celsius scales.)	deg
The symbol degK or degC may be used.	
dyne	dyn
electronvolt	eV
erg	erg
farad	F
foot	ft
footcandle	fc
The name **lumen per square foot (lm/ft²)** is preferred for this unit.	
footlambert	fL
If luminance is to be measured in English units, the **candela per square foot (cd/ft²)** is preferred.	
foot per minute	ft/min
foot per second	ft/s
foot per second squared	ft/s^2
foot poundal	ft·pdl
foot pound-force	ft·lbf
gal	Gal
1 Gal = 1 cm/s^2	
gallon	—
The gallon, quart, and pint differ in the US and the UK, and their use is deprecated. If necessary, use **gal** for gallon.	
gauss	G
The electromagnetic CGS unit of magnetic flux density. Use of the SI unit, the **tesla (T)** is preferred.	
gigacycle per second	Gc/s
See note for cycle per second regarding use of the new term hertz, in this case **gigahertz (GHz).**	
gigaelectronvolt	GeV
gigahertz	GHz
New name for gigacycle per second.	
gilbert	Gb
The electromagnetic CGS unit of magnetomotive force. Use of the SI unit, **the ampere (A)** or **ampere-turn (At)** is preferred.	
gram	g
henry	H
hertz	Hz
New name for cycles per second.	
horsepower	hp
hour	h
Time may be designated as: $9^h46^m30^s$.	
inch	in
inch per second	in/s
joule	J
joule per degree	J/deg
Unit of heat capacity.	
joule per degree Kelvin	J/°K
Unit of entropy.	
kilocycle per second	kc/s
See note for cycle per second regarding the new term hertz, in this case **kilohertz (kHz).**	
kiloelectronvolt	keV
kilogauss	kG
kilogram	kg
kilogram-force	kgf
In some countries, **kilopond (kp)** has been adopted for this unit.	
kilohertz	kHz
New name for kilocycles per second.	
kilojoule	kJ
kilohm	kΩ
kilometer	km
kilometer per hour	km/h
kilovar	kvar
kilovolt	kV
kilovoltampere	kVA
kilowatt	kW
kilowatthour	kWh
knot	knot
lambert	L
The CGS unit of luminance. Use of the SI unit **candela per square meter (cd/m²)** is preferred.	
liter	l
liter per second	l/s
lumen	lm
lumen per square foot	lm/ft^2
lumen per square meter	lm/m^2
lumen per watt	lm/W
lumen second	lm·s
lux	lx
1 lx = 1 lm/m^2	
maxwell	Mx
The electromagnetic CGS unit of magnetic flux. Use of the SI unit **weber (Wb)** is preferred.	
megacycle per second	Mc/s
See note for cycle per second regarding use of the new term hertz, in this case **megahertz (MHz).**	
megaelectronvolt	MeV
megahertz	MHz
New name for megacycles per second.	
megavolt	MV
megawatt	MW
megohm	MΩ
meter	m
mho	mho
IEC recommends the name **siemens (S)** for this unit.	
microampere	μA
microbar	μbar
microfarad	μF
microgram	μg
microhenry	μH
micrometer	μm
micromho	μmho
IEC recommends the name **microsiemens (μS)** this unit.	
micron	—
Deprecated; the name **micrometer (μm)** is preferred.	
microsecond	μs
microsiemens	μS
New name for **micromho (μmho).**	
microwatt	μW
mil	mil
1 mil = 0.001 in.	
mile (statute)	mi
mile (nautical)	nmi
mile per hour	mi/h
Although mph is common, it is not recommended.	
milliampere	mA
millibar	mbar
millibarn	mb
milligal	mGal
milligram	mg
millihenry	mH
milliliter	ml
millimeter	mm
millimeter of mercury (conventional)	mmHg
1 mmHg = 133.322 N/m^2	
millimicron	—
Deprecated; the name **nanometer (nm)** is preferred.	
millisecond	ms
millisiemens	mS
New name for millimho.	
millivolt	mV
milliwatt	mW
minute (plane angle)	′
minute (time)	min
Time may be designated as: $9^h46^m30^s$.	
nanoampere	nA
nanofarad	nF
nanometer	nm
nanosecond	ns
nanowatt	nW
nautical mile	nmi
neper	Np
newton	N
newton meter	N·m
newton per square meter	N/m^2
oersted	Oe
The electromagnetic CGS unit of magnetic field strength. Use of the SI unit **ampere per meter (A/m)** is preferred.	
ohm	Ω
ounce (avoirdupois)	oz
picoampere	pA
picofarad	pF
picosecond	ps
picowatt	pW
pint	—
The gallon, quart, and pint differ in the US and UK, and their use is deprecated. If necessary, use **pt** for pint.	
pound	lb
poundal	pdl
pound-force	lbf
pound-force foot	lbf·ft
pound-force per square inch	lbf/in^2
pound per square inch	—
Deprecated; although use of psi is common, it is not recommended. Use instead **pound-force per square inch (lbf/in²).**	
quart	—
The gallon, quart, and pint differ in the US and the UK, and their use is deprecated. If necessary, use **qt** for quart.	
rad	rad
Unit of absorbed dose in radiation dosimetry.	
radian	rad
rem	rem
Unit of dose equivalent in radiation dosimetry.	
revolution per minute	r/min
Although rpm is common, it is not recommended.	
revolution per second	r/s
Although rps is common, it is not recommended.	
roentgen	R
Unit of exposure in radiation dosimetry.	
second (plane angle)	″
second (time)	s
Time may be designated as: $9^h46^m30^s$.	
siemen	S
New name for mho. 1 S = $1\Omega^{-1}$.	
square foot	ft^2
square inch	in^2
square meter	m^2
square yard	yd^2
steradian	sr
tesla	T
1 T = 1 Wb/m^2.	
tonne	t
1 t = 1,000 kg.	
var	var
Unit of reactive power.	
volt	V
voltampere	VA
Unit of apparent power.	
watt	W
watthour	Wh
watt per steradian	W/sr
watt per steradian square meter	W/(sr·m^2)
weber	Wb
1 Wb = 1 V·s	
yard	yd

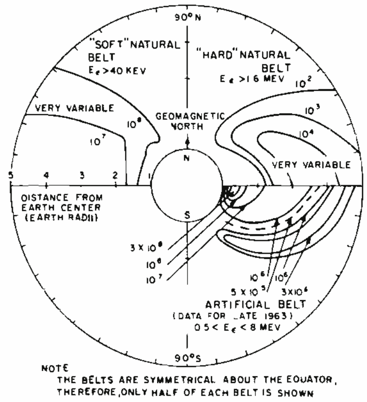

Fig. 1—Trapped electron belts, late 1963.

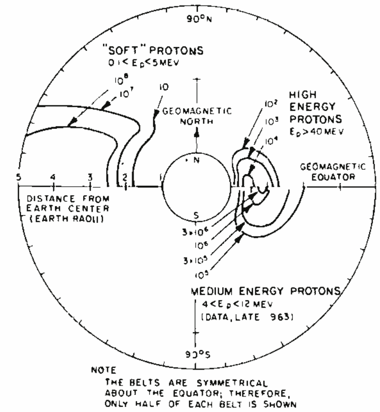

Fig. 2—Trapped proton belts, 1962-1965.

SPACE RADIATION

Its Influence on Satellite Design

Designing electronic equipment to withstand the damaging effect of radiation is an intricate problem in itself, but add this to the problem of designing a light-weight, complex spacecraft which must operate for at least six months in the relatively unknown, ever-changing space radiation environment, and the task becomes enormous. Each part must be considered separately, taking into account not only the expected radiation dosage but also the application and criticality of the component. This paper reviews some of the currently known information about this complex environment and establishes some general guidelines for designing electronic equipment for reliable operation in space.

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It would be very convenient if the author could write a book entitled "How to Design for Space Radiation Environments" for his colleagues in the satellite design groups. Unfortunately, this would be like writing a book for generals entitled "How to Fight a Battle." In neither case could the book be definitive because of the huge number of possible situations which arise in each field. In each case, an attempt to adhere rigidly to the directions provided would probably lead to error, since in fields like these—where so much still remains to be explained—unforeseen results are all too common.

Final manuscript received April 29, 1965.

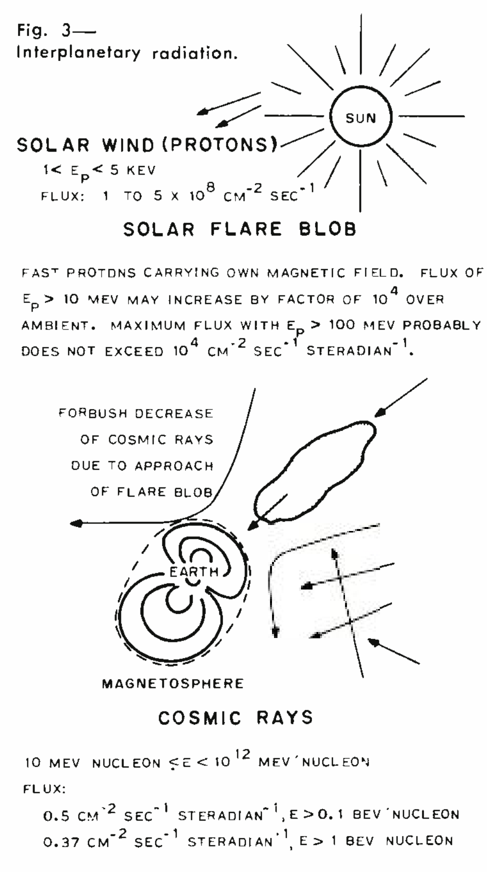
COMPLEXITIES OF DESIGNING FOR SPACE RADIATION

A classic sample of the kind of pitfall involved in designing for space radiation is provided by the planar transistor story. By growing an oxide coating on the surface of a silicon transistor wafer, designers thought that a near-final answer to "surface passivation" had been found—the oxide layer isolated the p-n junctions from air, moisture, and other damaging contaminants. But, when operated in a radiation environment, the transistor proved to be its own worst enemy. Ions present in the oxide layer are freed by the radiation, and act on the silicon surface in the same way as the contaminants which the designers were at pains to shut out.

Such complexity of result had been recognized even in the commonly encountered sources of radiation such as industrial x-rays, electron beams, nuclear reactors, and other isotope radiation sources. The problems are not special to space. It is just that in space, radiation intensities can be very high, and the following exceptional complications arise:

1) There is the unusual difficulty that the environment is remote, and as yet we cannot regularly get our equipment back, either to repair it or to check what phenomenon has caused a failure.
2) The environment is a very complex mixture of charged particles, mainly electrons, protons, and x-rays (the latter produced when electrons strike the satellite surface) moving at different velocities. Depending on location in the satellite and on the orbit type, any of these three radiation species may become predominant in the damage process. In addition, the satellite surface layers have to withstand the full blast of the sun's light—ultraviolet and soft x-rays.
3) Radiation in space is highly structured: terms such as *belts, blobs,* and *streamers* are common.

Fig. 3—Interplanetary radiation.



4) The radiation structures are not completely stable in time: the *belts* fill and deflate with solar activity, which occasionally reaches storm proportions. At this time, *blobs* break off from the sun and stream outwards.

5) Each orbiting satellite, as it passes into and out of the radiation structures, accumulates a unique pattern of radiation dose versus depth of shielding material and time. The number of orbits to choose from vary widely in ellipticity and in the altitude of the closest and furthest point. The orbital plane can lie in the plane of the equator, the poles, or anywhere in-between. If the orbit is very far-ranging (10 to 100 earth radii), it can even be important whether the ellipse points towards or away from the sun. If the orbit of interest is an earth-escape orbit, such as MARINER's, then we are penetrating into regions of space where very little is known about the radiation structures.

6) Very little weight can be spared for shielding.

This introduction should serve to place the subject in that painful category—too complex for simple engineering analysis, too serious to be ignored by engineering projects. Ideally, the engineer should be able to avoid the above problems. He should have available a list of components known to be sufficiently "hard" for his particular mission and, without worrying about the details of environment, he should be able to build with them. This, unfortunately, is not the case now, mainly because:

1) radiation testing is expensive and often lengthy, and therefore has never covered all the desirable components.
2) electronic components proliferate (and obsolesce) rapidly;
3) the properties which provide high radiation resistance in a component may limit it in some essential electrical parameter; and
4) the wide ranges of dose, dose rate, particle type, and energies present in space make it impossible to construct a list of components which are invariably "hard" against all conditions

Thus, the "expert" may remain a necessity for some time in designing for radiation. This article aims to provide some insight into the issues involved and into the peculiar mixture of empiricism and science from which the expert must derive his approach to these issues.

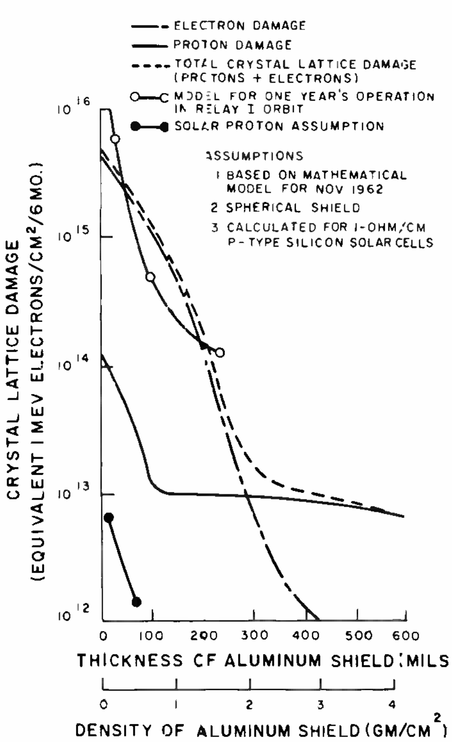


Fig. 4—Crystal lattice (minority carrier lifetime) damage profile—1962 model for 6 months in a 750-nautical-mile polar orbit behind a given shielding thickness (strictly, only applies to boron-doped silicon).

INTRODUCTION TO THE ENVIRONMENT

Because all parts of the space environment are in a continual state of change, either rapid or slow, no published source is ever completely up to date. For analysis, one must "freeze" a model of the space environment at a particular time, and allow for the inevitable changes that will occur as a result of the passing of time. Figs. 1 and 2 show such a model. Refs. 1 through 5 contain some key reviews on the current space environment.

Trapped Radiation

The contours shown in Fig. 1 and 2 represent a cross section, through a toroidal zone, of particles "bottled-up" by the Earth's geomagnetic field. The axis of the toroid is the geomagnetic north-south axis. Note that the information in these maps does not present a connected story of the environment. The maps are simply analyses, by various experimenters, of existing particle detector results, but these results leave important gaps in our knowledge. For example, the fact that no maps exist for protons between 12 and 30 MeV does not imply that protons do not exist in this important energy range; that range has simply not been fully explored. All of the maps, when superimposed, give a rough idea of the present total situation. The belts are in dynamic equilibrium, and the electron contours, in particular, vary considerably with solar activity; in fact, the belts may be less like a bottle than a "leaky bucket" for electrons injected into them. For example, recent Russian explosions caused sharp and local increases in trapped electron flux intensity, which then decayed over a few weeks. However, the artificial belt created by detonation of the U.S. STARFISH nuclear bomb (particularly the peak zone at an altitude of about 2,000 miles along the equator) is, as will be described, much more stable both in shape and intensity.

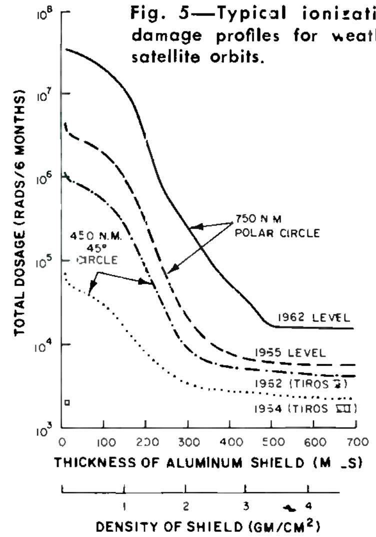


Fig. 5—Typical ionization damage profiles for weather satellite orbits.

Trapped Electrons

The explosion of the STARFISH bomb in July 1962 increased the radiation problem for near-earth satellites in several ways. As shown in Fig. 1, fluxes were increased by several orders of magnitude; but, also, while the electrons in the previous belt were "soft" and easily stopped (by perhaps 100 mils of aluminum), the new fission electrons are "hard" and can penetrate into the center of most component boxes. Even after considerable decay of this belt over the last three years (see the dashed line of Fig. 5), the operating life expectancy of satellites is still several times shorter than would have been the case before STARFISH—perhaps as much as ten times shorter for orbits strongly intersecting the artificial belt.

Electrons, therefore, previously of less importance, may, for a long time, be the predominant problem for boxed components. (See Fig. 4 for the relative damage capability of particles). These artificial electrons have energies of 0 to 8 MeV with a "fission spectrum" type of energy distribution, such that about 10% are absorbed by 5 mils of aluminum, 90% by 200 mils, and 99.98% by 500 mils. (As the density of a material goes up, its stopping power goes up nearly in direct proportion; e.g., 66 mils of stainless steel is roughly equivalent to 200 mils of aluminum because it is three times as dense. See Refs. 2 to 8.)

DR. A. G. HOLMES-SIEDLE received a BA from Trinity College, Dublin, in 1954, and a PhD in Organic Chemistry from Cambridge University, England, in 1958. He conducted postdoctoral chemical research at the Cambridge University Chemical Laboratories from 1958 to 1960, studying the transfer of energy in biological and chemical systems. In 1960 he joined the Advanced Projects Group of Hawker-Siddeley Aviation as a project engineer cooperating in preliminary design studies of communication satellite systems and lunar vehicles; in these system studies he specialized in the effects of environment on components and humans, simulation of space environment, and telemetering of scientific data. In 1962, he joined the Physical Research Group of the Astro-Electronics Division where he is doing research on radiation damage and scientific instrumentation of satellites. Such work includes experimental research on radiation effects in materials, analysis of the space radiation environment and its effect on space systems, irradiations of satellite components and systems designed for NASA satellite projects, definition of radiation effects criteria for RCA spacecraft, and engineering studies and research on space radiation detectors. Dr. Holmes-Siedle has been assigned as coordinator of radiation experiments and representative for this information at the Astro-Electronics Division. He is a Fellow of the British Interplanetary Society and a Member of the IEEE and IEEE Group on Nuclear Science. He has published several research notes in chemistry, technical articles on space technology and a book on the haem enzymes.

Trapped Protons

The protons in space have a wider energy distribution, from 0 to 1,000 MeV. A proton of 4.5 MeV will just penetrate the 6-mil cover glass of a solar cell, but a 40-MeV proton will penetrate about 340 mils of aluminum; and, to exclude protons of 100 MeV, 1.5 inches of aluminum would be required (Refs. 2 to 11.) Shielding against proton damage is further complicated because the trapped proton fluxes may increase as the sun's activity increases. (The peak activity of the 11-year solar cycle will occur about 1969.)

Solar Radiation

Even with heavy shielding, the problem from electrons is not completely eliminated. Electrons (but not protons), when slowed down in any way, emit some of their energy as electromagnetic radiation called *bremsstrahlung* (brake radiation). In the artificial electron belt, the bremsstrahlung photons are in the range of energies usually known as gamma rays, and will penetrate 300 mils of aluminum with only a 10% loss of intensity. The intensity of bremsstrahlung generated is proportional to the atomic weight of the target material. Therefore, fortunately, aluminum and magnesium are moderately inefficient in generating gamma rays, and plastics even less so.

Some insight into the effect of shielding on damage (explained in detail later) can be gained from Fig. 4 and 5; these effects are calculated using stopping-power data of the type outlined above.

Solar Radiation—High-Energy Protons

Satellites in polar orbits, high-latitude orbits, or orbits beyond the magnetosphere will encounter moderate fluxes of high-energy solar protons during solar flares (see Fig. 3). These protons are softer than the Van Allen-Belt protons, but may produce higher annual fluxes at the vehicle surface than those in the Van Allen Belt, since solar protons are "funnelled" in at the magnetic poles. These protons produce the well-known *polar cap absorption* phenomenon in the ionosphere, which has a strong disturbing effect on radio communications.

INTERPRETATION OF DAMAGE DATA

Sensitivity of Components

The effects of particles which penetrate the cases of components are due mainly to either the displacement of atoms from a crystal lattice (which strongly affects semiconductors), the breaking of chemical bonds (which strongly affects plastics), or the excitation of electrons (which affects mainly glasses and photographic films). Excluding photographic film, the most sensitive items are transistors, solar cells, optical plastics, and glasses. As a rule, insulators, structural plastics, resistors, and diodes and capacitors are at least two or more orders of magnitude less sensitive. However, a component is as sensitive as its system application dictates. If large changes in performance can be tolerated, the component is, by definition, less sensitive, and the system is "hard" in this respect. This factor should be taken into account early in system design; large performance tolerances must be allowed to produce a radiation-hard system.

Effectiveness of Particles

There are no general rules which can be applied to the relative effectiveness of protons, electrons, neutrons, and gamma rays in their damaging effect on devices or materials. Because these particles vary greatly in their penetrating power, device configuration is a major factor in determining a component's hardness to a particular type of radiation. For example, 1-MeV protons are very effective in damaging *bare* solar cells, where the active region is very near the surface, but they will never reach a glass-shielded solar cell or a normal transistor, where the wafer is within a metal can. On the other hand, fission electrons will penetrate the can with little attenuation. Gamma rays of 1 MeV will largely pass through the silicon wafer, leaving a much smaller number of crystal defects per particle than will 1-MeV electrons. (This topic will be considered further when we attempt to make damage predictions for a satellite on a specific reference mission.)

A very rough but working assumption for the relative damaging effects of particles on *semiconductor components only* could be:

1 proton/cm² (10 MeV)
≡ *4 reactor neutrons/cm²* (> 1 MeV)
≡ *10³ electrons/cm²* (1 MeV)

Gamma rays cannot be equated simply with particles. Gamma rays are photons with virtually no momentum;

TABLE I—Component Sensitivity Under High-Energy Radiation

6-Months Damage Levels for Given Locations in Typical Weather Satellite (1962 Levels)	Equivalent 1-MeV Electron Fluxes (dem)	Electrical Effects from Crystal Lattice Damage after 6 Months in Orbit*	6-Months Damage Level for Given Locations in Typical Weather Satellite (1962 Levels)	Ionization Dose Levels (rads)	Effects from Ionization Damage after 6 Months in Orbit*
				10^9	— — —
At Surface → Under Solar-Cell Hat →	10^{16}	Thermistors affected, gain of field-effect transistors affected; 50% loss in UHF (100Mc/s) Si transistors; and forward resistance of diodes affected	At Surface →	10^8	Leakage of resistors; capacitors affected. Insulation leakage
			Under Solar-Cell Hat →	10^7	Glass turns "beer-bottle" brown
Inside thin box →	10^{15}	25% degradation of n-p solar cells	Inside thin box →	10^6	Serious I_{CBO} and gain effect in transistors
Inside thick box →					
Behind 400-mil Shield →	10^{14}	50% loss in HF (5Mc/s) Si transistors; 25% degradation of p-n solar cells	Inside thick box →	10^5	5-20% loss of transmission in glass
	10^{13}	50% loss in LF (500kc/s)Si transistors	400-mil Cover →	10^4	I_{CBO} and gain affected in some transistor types

* 750-nautical-mile, circular, polar orbit

therefore, they themselves cannot interact with, and displace, an atom in a crystal. However, they do generate high-energy *Compton electrons* in appreciable quantity (1 rad of Co^{60} gamma rays would produce about 10^7 Compton-electrons/cm^2, of energies up to about 1.3 MeV in the steel cap of a transistor). Thus, high doses of gamma rays produce some crystal damage, but the amount will depend upon details of the component's shielding configuration. This Compton-electron equivalence is used in Fig. 9 to relate some experimental results.

Space vs. Accelerator Damage

In calculating damage due to given space radiation fluxes, certain other factors must be considered. The omnidirectional fluxes of space must often be compared to damage caused by the unidirectional fluxes obtained from a particle accelerator. The direction of particle approach can be important. Glass solar cell covers are more effective against omnidirectional flux than a normally-incident beam of particles, and, in space, no particles at all may get through from the inner side of the solar cell panel. The same reasoning applies to other components. Thus, an omnidirectional flux of 10^{12} ten-MeV-protons/cm^2 may be considerably less effective on glass-shielded solar cells than 10^{15} electrons normally incident on the same cell (i.e., DENI damage less than 10^{15}).

Extrapolating from Existing Neutron-Gamma Data

For some electronic and optical components, sufficient device and damage theory exists to make theoretical estimates of parameter changes resulting from given damage levels, without requiring further tests. But, even these estimates may prove incorrect due to some unpredictable but overriding effect incidental to the basic device structure (e.g., leakage in the passivating layer of a semiconductor). For other components, no suitable theory may exist, and we may have to rely completely on empirical data, obtained either by extrapolating existing test results or instigating special experimental work.

On being presented with a radiation effects query on a satellite component, the expert often finds that the only radiation tests which have been reported for that component employed reactor neutron-gamma radiation. If this is the only data available and no time for more relevant tests can be spared, it is sometimes possible to "extrapolate" to (i.e., make an informed guess on) the probable damage to the component in orbit, based on: 1) the geometry of the device, 2) the known mechanism of the damage, and 3) the results of some strictly comparative irradiations of similar components under electrons, neutrons, or gamma-rays.

To make this so-called extrapolation from neutron-gamma test results to possible parameter changes in space, one must first decide whether the device or material is such that damage will be caused by crystal-lattice displacements (which can only be affected by particle collisions) or by ionization or excitation of electrons in the material struck (when ionization can be produced equally well by x-rays, gamma-rays, or charged particles). Examples of crystal-lattice damage are permanent transistor gain degradation and solar-cell power loss. Examples of ionization damage are deterioration of organics, semipermanent transistor gain degradation, transistor leakage, and browning of glass.

Table I is a list of such changes and their levels of onset. Comparison of this table with Fig. 4 and 5 will show approximately how soon such effects should occur in a particular location in a satellite in the given orbit.

RCA Standardizing Notice 7-7-216 (Ref. 22) contains an extrapolation from a survey of published neutron-gamma test results (see Refs. 13-16) of what the worst probable changes will be in some commonly used devices. In this analysis, it was assumed that if the damage was lattice type (as for diodes), one fast reactor neutron would have about the same damaging effect as 300 one-MeV electrons, and that the gamma rays present in the test environment would not contribute significantly to the damage. Alternatively, if the damage were likely to be from pure ionization (say, as for capacitor dielectrics), then Fig. 5 would be used to find the likely ionization level in orbit. This level could then be compared with results obtained under reactor-gamma radiation, ignoring the neutron component present.

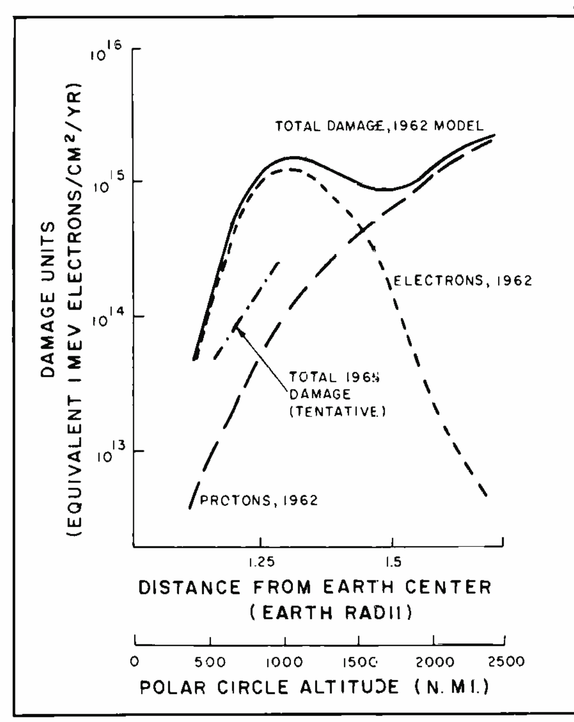
Damage vs. Depth

To determine the effect which a given quantity of external, or *surface*, particle flux will have inside the vehicle, some quite-complex conversions must be made.[12] As indicated in Table 1, there are at least two distinct types of mechanism causing component degradation: *ionization* and *crystal-lattice* damage. As shielding is interposed between the component and the outside environment, each decreases at a different rate. Crystal-lattice damage for a given particle flux will, in fact, vary even with the type and doping concentration of the semiconductor crystal. Therefore, strictly speaking, each semiconductor component type in the satellite requires its own damage-depth curve. A typical and fairly general curve is shown in Fig. 4. This shows how the bulk damage (atomic displacements caused by the charged particles of the environment) in the base region of a typical n-on-p solar cell would vary as more and more shielding, in spherical shell form, is interposed between the cell and the environment. It shows how the contributions of various particles differ with depth and can be added to give a total-damage picture.

The damage units of Fig. 4, *equivalent 1-MeV electrons* or, more accurately, *damage-equivalent, normally incident 1-MeV electrons/cm²* (DENI for short) represent an attempt to find a universal unit for semiconductor damage into which all types of bulk damage occurring in a component can be converted, and then the total summed. For example, a solar cell receiving a radiation dose of 10^{12} ten-MeV-protons/cm^2 (normally incident) is affected as though it received 10^{15} normally-incident 1-MeV-electrons/cm^2 (see *Effectiveness of Particles*); thus, this proton-irradiated cell is said to have suffered a damage of 10^{15} DENI units. The total damage due to high-energy electrons, protons, etc., expressed in DENI's, can then be summed to make a fair prediction of total damage.

The *rad* is a measure of the ionization which radiation has produced in a mate-

Fig. 6—Crystal lattice damage in p-type silicon vs. polar orbit altitude: 60-mil Al shield (NASA E8U-1962 environment).



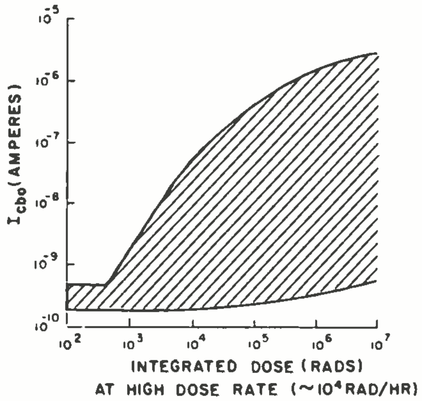


Fig. 7—Possible ranges of collector-base leakage increase in modern transistors.

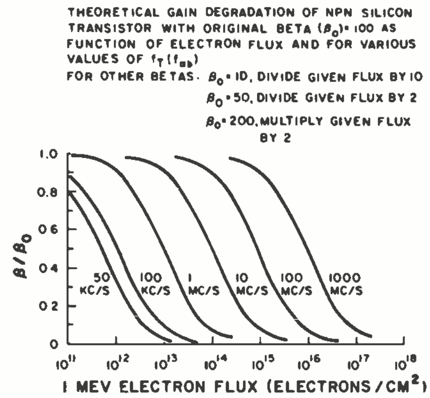


Fig. 8—Gain damage in silicon transistors.

rial. Each ion pair requires about 3.5 MeV for its production. A rad is the deposition of 100 ergs per gram of material, and can thus be calculated to produce over 10^{12} ion pairs per gram of material. Tables are available for the ionizing efficiency of charged particles of given energies. Thus, particle flux can also be converted into a convenient and widely usable unit of ionization damage.

A SET OF PREDICTIONS FOR A TYPICAL SATELLITE MISSION

To give a quantitative demonstration of radiation effects in space, we will consider a typical satellite and its mission and make a set of damage predictions for the electronic and mechanical components used.

Reference Mission

For this paper, the "reference mission" is a circular polar orbit at an altitude of 750 nautical miles: this orbit has quite a high level of radiation. As indicated in Fig. 6, many of the most commonly used orbits encounter lower flux levels than the orbit selected, and only a few are at higher levels.

The reference mission is selected because it is that intended for use in operation weather or observation satellite systems. The 750-nautical-mile polar orbit is probably the maximum altitude to which the satellite can be pushed on the "underside" of the Van Allen belt and still give assurance of from six months to a year of trouble-free operation by such complex equipment as TV cameras and tape recorders—without strong design compromises. It should be noted, however, that RELAY I had a similar integrated radiation flux, but operated for *well over a year* (see Fig. 4). On the other hand, TELSTAR I, in a very similar orbit, *failed* in less than 3 months from the radiation-induced leakage of a transistor.[12]

To make sense of a reference mission, the design of the satellite must be specific, since the damage predictions will depend greatly upon its configuration. Here, except for the solar cells, we will assume that all the components are surrounded by an average of 100 mils of aluminum on all sides. This is a very conservative for a satellite design which has its solar cells wrapped around the electronics, but less than conservative for more advanced designs with the solar cells mounted on paddles, and with only thin thermal shields and foam-rubber structures separating the electronics from outer space.

Radiation Levels

For this six-month mission, the accumulated surface flux of electrons from the belts will be 2×10^{15} electrons/cm² (energy, 0.5 to 8 MeV) and 2×10^{11} protons/cm² (energy, >4 MeV). The damage levels for components behind the 100-mil aluminum shield will be 2×10^{15} DENI and 2×10^{7} rads. Readers who are familiar with the significance of these radiation levels will realize they are high and can cause significant damage. They should remember, however, that: 1) these are calculated on a model which probably only existed in 1962 (e.g., for TELSTAR, RELAY I, etc.) and levels are now reduced; 2) components in older-type satellites "pick-up" a lot more than 100-mil equivalent shielding of aluminum (TELSTAR was estimated to have up to 500 mils around most components); 3) the reference levels are based on NASA's conservative 1962 upper estiamate; NASA's lower estimate is about *three times* lower than this. Therefore, these are worst-case levels and, where found necessary, the levels can be considerably improved by shielding and other means. They are used here because modern satellites are employing progressively thinner structural elements and because another nuclear explosion like STARFISH coud restore the severe conditions of 1962.

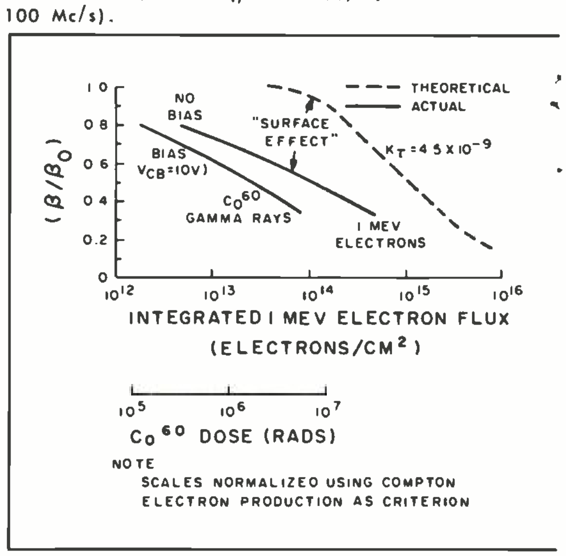
Solar Cells

Solar cells are always the least shielded of the semiconductors on a spacecraft. However, being simple devices, their power degradation is comparatively easy to predict and, unlike transistors or diodes, their degradation (if planned for) does not lead to catastrophic system failure, but only to a reduction in the operating time available. In the six-month reference mission, using the usual 6-mil fused-silica cover glass, power efficiency loss of 1-ohm-cm, n-on-p solar cells would be 35 to 40% (p-on-n cells would lose well over 50% of their efficiency on this mission). Although Fig. 4 is not very accurate at low shielding values, it can be seen that the damage contribution of medium-energy protons becoming heavy behind shielding only a few mils thick, perhaps approaching more than half the solar-cell damage incurred.

Transistor Current Gain Degradation

Transistors are the designer's major problem. The only effect predictable by device theory is gain loss by permanent semiconductor lattice damage in the base region (see Fig. 8); but, unfortunately, this effect is frequently overshadowed in silicon *planar* transistors by a surface-linked loss of gain, which sometimes starts at a flux level fifty times lower than that at which bulk damage becomes effective (or fifty times earlier in time in orbit). Fig. 9, which illustrates this effect, was observed in an experiment by the author and coworkers;[17] others have observed the same effect.[18,19] This surface-linked loss of gain appears related to, but not identical to, the leakage-current effect described in Ref. 20 for silicon mesa transistors.

Fig. 9—Comparison of actual degradation (with and without bias) with theoretical degradation for an NPN silicon planar transistor under radiation (β_0 = 100, f_T = 100 Mc/s).



This damage to gain is more permanent than the leakage effect and is sometimes affected by the biasing levels and the duty cycle of the transistor. While the damage is stable at room temperature, baking of the transistor (say to 250°C) may often correct much of the damage. Unfortunately, this damage is *not* easily predictable, and depends upon the details of the surface processing used by each manufacturer. The only certainty about such damage is that it is most effective at low operating current levels. A certain transistor, operated with a collector current of 10 *milli*amperes may not experience any appreciable loss of gain, while the same transistor, operated at 10 *micro*amperes, may have lost all its gain. This points to a damage mechanism which involves the upper surface of the silicon wafer.

Transistor Leakage Currents

The collector-base leakage current (I_{CBO}) of a transistor in the reference mission could increase by over a thousand times if bias were continually applied to the transistor for the entire six months. Moreover, shielding would not necessarily completely eliminate this leakage problem, since the remaining gamma rays can just as readily produce increases in I_{CBO} (see Fig. 5).

It is not possible to draw typical I_{CBO} curves because, even for a particular type of transistor, the variations are too great between samples of the same type number. However, Fig. 7 gives a rough idea of the order of magnitude of the effect. Clearly, this problem must be studied during satellite circuit design, and, wherever possible, trial irradiations of *operating* transistors must be carried out.

Transistor Annealing

Serious thought is now being given to pre-irradiation processing of flight-model transistors. For this procedure, a group of transistors would be irradiated under Co^{60} gamma rays to mission radiation levels and their parameters measured. The poor samples of a type would be rejected, and the good ones hopefully baked back to life at about 300°C.

Significance of Transistor Effects

It was mentioned previously that transistor damage causes more concern than solar-cell damage. The reason is that with a solar-cell power supply, the effect of radiation is fairly standard from cell to cell and takes the form of a smooth, predictable, decrease of output power: most of the change being in current, not voltage. Intelligent regulator design and power budgeting can handle these changes, and the technique of doing so has been highly developed and proven in flight.

Transistors, on the other hand, are used in complex circuits, where the actual circuit tolerances to a given change is not easy to establish, and where the reduction of gain below (or rise of leakage above) a certain value may lead to sudden, complete failure of the circuit. There is no analogy to the "power budgeting" possible in solar-cell power supplies. Also, the performance of a transistor under radiation or aging is more complex and unpredictable than the performance of solar cells. The main problem is that the surface-linked radiation effects are unpredictable. Nevertheless, there is often an urgent need to predict these effects without extensive testing of the device in question. Such predictions, using test data from other transistors, could result in as much as a fifty-fold error in estimating the flux dose needed to degrade a given transistor. On a real-time scale, we cannot be sure whether a transistor is going to reach, for example, 0.45 original beta in 18, 180, or 900 days; understandably, project managers are not very happy with such answers. The alternative of extensive testing may be equally inconvenient. Clearly, the problem is no longer solved by simply "derating"; probably, careful shielding and selection are the only sensible approaches to long-life design.

Some favorable irradiation results have been obtained with field effect transistors[21] but it also appears that bias levels are critical in determining the amount of radiation damage caused.

Teflon and Plastics

Because of its excellent mechanical properties in vacuum and during ground handling, the qualifications of teflon for space use have been the subject of many studies and much argument. Despite several misleading comments in the literature, teflon has never been shown to evolve appreciable amounts of fluorine, corrosive gases, or any gas under radiation in vacuum, and retains its electrical and mechanical properties as well as, or better than, other insulators.

While some plastics exhibit electrical changes at levels as low as 10^5 rads, mylar and polystyrene have stable properties up to 10^8 rads; thus, we can predict "no change" for these materials in the reference mission. However, direct tests under radiation are desirable for any critical application.

Lens Glasses and Other Transparencies

Recent tests by the author and co-workers have provided a wider perspective on the behavior of lens glasses and other transparencies under space radiation; these tests demonstrated that by the time the mission dose of 10^7 rads (behind 100 mils of aluminum) is reached, the lens glass would be a very deep brown—darker than a beer bottle in color. To bring the overall dosage level of the glass into the acceptable 10^4-rad region requires 300 to 500 mils of aluminum. Fortunately, lenses are usually housed in thick brass or aluminum barrels, which may provide enough side-shielding. The back obviously presents no difficulties—the front is the only problem. The method used so far has been to mount an optically flat filter of ultra-pure silica at the front surface. With such shielding (say ¼ inch thick), a TV camera lens on the reference mission should experience a transmission loss of about 20% in the wavelength region from 5,000 to 7,000 angstroms (the range used by TV cameras in space).

Recent tests have demonstrated a striking property in some lens glasses: a complete lens system, given about 10^5 rads of gamma rays for 10 days, showed considerable transmission loss. However, after the len was allowed to remain on the shelf for three months it had recovered about 75% of its transmission; the glass had annealed at room temperature. Intense light and heat (such as in space) should make this repair process even more rapid.

Because the TV tube glass, although better protected, is slightly more sensitive than lens glass, an additional transmission loss of 5% may be expected. The sensor material is not affected at these dose levels.

Other Components

Ref. 22 contains degradation estimates (developed from existing neutron-gamma data[16]) for some other components for which little helpful device theory exists. In all cases, the results quoted are made very pessimistic, and can only be regarded as "flagging a problem" for the engineer who knows what tolerances he has in his circuitry.

SOME RULES FOR SHIELDING SATELLITE SYSTEMS

Clearly, the most sensitive components in a satellite should be surrounded by as much shielding as possible. This can be achieved by placing them in the center of their equipment boxes, and, if possible, bunching several equipment boxes so as to produce mutual shadowing (this was planned from the beginning in TELSTAR). With present particle energies, one should aim ideally at surrounding sensitive components with the equivalent of at least 300 mils of aluminum, which will eliminate most of the electrons. The structure itself may be adapted to provide shielding; the simplest means being to thicken the satellite skin and employ the extra weight as rigid structure, thereby eliminating some internal structural girders. Necessary girders or tubes could, perhaps, house ultra-sensitive components inside them; Fig. 10 illustrates.

Potting material can also provide an important amount of shielding; 0.5 inch of pure polymer may attenuate space electron fluxes by as much as 90%. A heavy filler will increase the attenuating power.

CONCLUSION

The radiation problem in space, previously significant, has been greatly increased by the artificial radiation belt, and will present a serious barrier to long-life operational satellites at certain altitudes for several years. However, techniques for circumventing the problem are maturing. The constraints that radiation places on a satellite system, including orbit selection, should be studied in the earliest stages of a project, and weight should always be allowed, if possible, for radiation-effect monitors in high-radiation missions.

It can be seen that even for rather tolerant circuits, radiation effects in space may be sufficiently high to cause malfunctions. However, by the careful selection (possibly screening) of components, careful geometrical arrangement, and, if necessary, the addition of a few pounds of special shielding, the radiation problem can usually be overcome. It should be noted in passing that many conventional circuit designs can be replaced by others using very highly radiation-resistant components such as tunnel diodes and ferrite-core logic.

Any system which contains transistors has a fairly low threshold for radiation because of the gain loss and leakage increase. It is probable that the close-packing of elements into integrated circuits will decrease the shielding-weight problem by reducing component volume; but the use of such units will tend to increase the individual radiation-effect problem of the circuit wafer by increasing the possibilities of leakage, noise, junction breakdown, and other minority carrier lifetime effects, resulting from the complexity of doping patterns spaced closely on the wafer.

As mission life and mission complexity increase, it is not likely that total component-box volume will decrease. Hence, shielding problems may stay on the same magnitude but become more sophisticated. Because modern structural techniques are reducing the need for heavy structures, the 100-mil-aluminum all-around shielding, used in this paper as the typical natural shielding for spacecraft skin and box structures, while pessimistic for current weather-satellite designs such as TIROS, may be optimistic for advanced spacecraft design. Here, components are sometimes supported only by foam potting material inside spacecraft skins made of thin fibreglass. The overall conclusion is that an experimental irradiation program, as well as other types of research and development on radiation problems, should usually accompany satellite design work. Design considerations should include radiation as a fundamental design parameter of the vehicle system and be dealt with by true systems and reliability engineers, as well as by scientists.

Summarizing some radical circuit-design guidelines:

1) Select transistors, with very great care, for the narrowest bases feasible and for special surface beta and I_{CBO} resistance (possibly the modern silicone-encapsulated units will show an improvement over present transistor performance). During circuit analysis, allow for the inevitable beta loss as well as other component changes.
2) Pay attention to the surroundings of the more sensitive units, using heavy equipment as "shadowing" mass, and possibly employing potting material for local shielding.
3) Pay attention to the past performance of components in space vehicles.

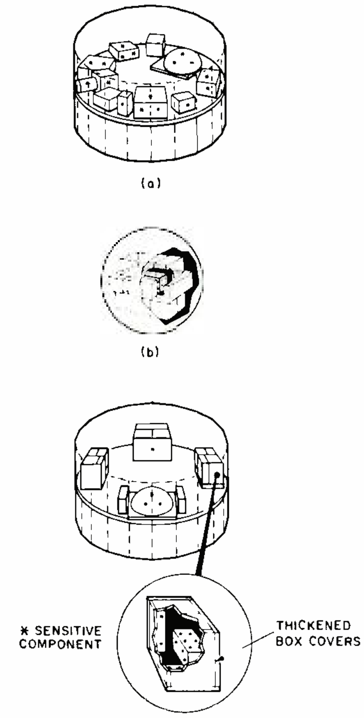


Fig. 10—Satellite component layouts, comparison of radiation hardness. a) typical satellite layout, b) ideal satellite layout for optimum mutual radiation shielding (possibly 10X better than (a), i.e., 10X longer life), and c) compromise layout for radiation hardening (possibly 3X longer life).

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TUNNEL-DIODE MICROPOWER LOGIC CIRCUITS

Small size and low power consumption are frequently prime requirements in space-system electronics. The realization of low-power circuits will depend on the development of an active element which is capable of providing power gain at the microwatt level. Tunnel diodes are attractive devices in micropower logic circuits as they provide high speeds, with good noise immunity and radiation resistance, at microwatt levels. Tunnel diode micropower logic circuits have been constructed and operated at 10-Mc/s repetition rates, dissipating 160 μW of power. Circuits appear feasible which will provide repetition rates of 3 Mc/s, dissipating 3 to 7 μW of power.

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SMALL size and low power consumption are frequently prime requirements in space-system electronics. The packing density of microelectronic circuits is often limited by the dissipation of the power generated in the devices. In addition, reduction in the size of circuits operating at conventional power levels will bring only small gains as compared to the fixed size and weight of their power supplies. Thus, a great need exists for a drastic reduction in power-supply requirements.

The realization of low-power circuits depends on the development of an active element which is capable of providing power gain at the microwatt level. The recent advances in planar technology has extended the useful operating current of transistors to the microampere range, and the use of these transistors in microwatt logic circuits has been described.[1-3] More recently, the use of complementary n- and p-type MOS transistors in nanowatt logic circuits has been reported.[4] Another active device which holds great promise for fast micropower logic is the tunnel diode.

The use of tunnel diodes in high-speed digital circuits is well known. Several laboratories have developed computer logic circuits which make use of the very high speed switching property of tunneling and the inherently bistable characteristic of the tunnel diode. *What is much less generally known, however, is that speed can be traded off against power requirement in tunnel diode circuits.* Further, the reduction of power dissipation is far from linear with loss of speed, as seen by the logic circuit comparison in Table I; while speed has gone down by a factor of 35 to 70, the power requirement has gone down by a factor of 600.

Final manuscript received January 21, 1965

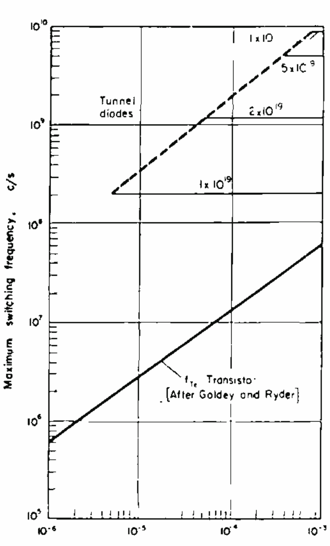
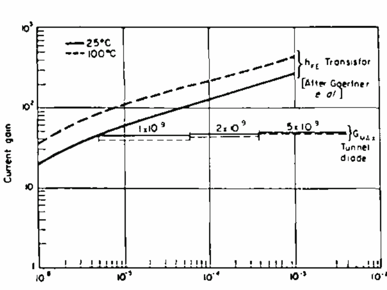


Fig. 1—Maximum switching frequency of Ge tunnel diodes and bipolar transistors vs. current.

Fig. 2—The variation of the current gain of transistors and Ge tunnel diodes with current level at 25°C and 100°C



DEVICE CONSIDERATIONS

Fig. 1 shows the maximum switching frequency of germanium tunnel diodes as a function of current, compared with the data of Goldey and Ryder[5] for a bipolar transistor. For low-power operation, the basic frequency limitation of the transistor is one of junction area; thus small emitter and collector capacitances are necessary to achieve high speed switching at low power levels.

For tunnel diodes, the maximum switching frequency is independent of junction area, and can be approximated for germanium diodes by:

$$\text{Maximum Switching Speed} = \frac{1}{t_r} = \frac{2I_p}{C} \quad (1)$$

where: I_p is the peak current in milliamperes, C the junction capacitance in picofarads, and t_r the time in nanoseconds. Assuming junction diameters of 0.1 mil, which can readily be achieved with electrolytic etching techniques, I_p will be limited by the current density of the tunnel diode. The data in Fig. 1 are for tunnel diodes ($p = 1 \times 10^{19}$ to 1×10^{20}, $n = 4 \times 10^{19}$ atoms/cm^3) with current densities ranging from 100 to 16,500 A/cm^2.

The variation of the current gain of germanium tunnel diodes and micropower transistors with current level is shown in Fig. 2. The transistor data is that of Gaertner, et. al.[6] for devices whose design had been optimized for microwatt operation. The maximum current gain, G_{max}, of the tunnel diode is[7]:

$$G_{max} = 1 + \frac{1 - \frac{I_v}{I_p}}{2\Delta I_p} \quad (2)$$

where: I_p and I_v are the peak and valley current respectively, and ΔI_p the peak current tolerance, which is assumed to be ±1%. The slight differences in current gain of the tunnel diodes with different p-region carrier concentrations are due to small variations in their I_p/I_v.

The effect of elevated temperature on device performance is to limit the tunnel

TABLE I—Typical Comparison of Tunnel Diode Logic Circuits

Parameter	50 mA Tunnel Diode	0.5 mA Tunnel Diode
Capacitance, pF	5.0	2.0
Device Switching Time, ns	0.05	2.0
Logic Delay In Gate, ns	0.5-1.0	35.0
Power Dissipation Per Gate, mW	60-140	0.16

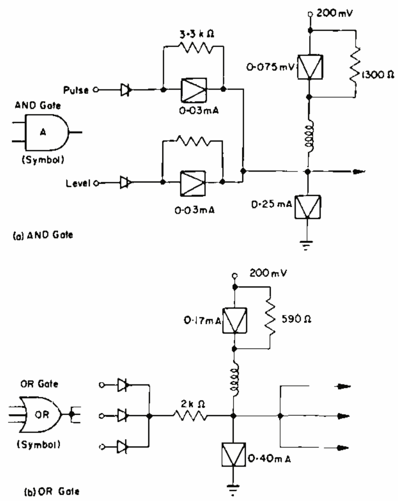


Fig. 3—Typical micropower tunnel-diode logic circuits.

diode current gain through a reduction of I_p/I_v, while the minimum usable emitter current of micropower transistors would be limited by the resultant high junction leakage currents. With respect to radiation resistance, it has been demonstrated that tunnel diodes can withstand neutron fluxes of the order of 10 to 100 times greater than that which transistors can tolerate.

MICROPOWER LOGIC CIRCUITS

Tunnel-diode logic circuits can be designed to operate either in the monostable or bistable mode. Fig. 3 illustrates a typical *and* and *or* micropower circuit.

Both of these circuits operate in the monostable mode. This mode of operation is characterized by the triggering of the tunnel diode from its low state to its high state by the application of the proper input signals. The output is in the form of a pulse with a recovery or inactivated region which follows the pulse output. An *or* gate is formed by tunnel rectifiers coupling multiple inputs to the gate, as shown in Fig. 3b. An *and* gate is formed by adding current limiting elements in series with the input tunnel rectifiers to control input current and improve tolerance requirements for the circuit (Fig. 3a). Low power is obtained from a low voltage bias (200-mV) on the stages. This low voltage bias with a tunnel diode and resistor in parallel provides a constant-current bias region for the tunnel-diode stage when it is in its low state. The biasing arrangement for the two gates is shown in Fig. 4. A tunnel diode and resistor combination is selected so that the resistor equals the negative resistance of the tunnel diode in its linear region. The resulting combined characteristic has a region of constant current which is chosen to provide the desired bias current for the tunnel diode. In the case of the *or* gate, this bias current would be chosen as close to the peak of the tunnel diode as tolerance, temperature, and noise parameters would allow. The constant-current region of the biasing network relaxes the tolerance requirements for the 200-mV supply voltage with considerable variation possible without affecting the bias current. For the *and* gate, the value of the biasing current is reduced so that switching will not occur with only one input present. However, when both inputs occur in coincidence, the circuit is triggered and an output pulse is produced. The output pulse is approximately 300 mV in amplitude and the pulse width is determined by the size of the inductor and the peak current of the tunnel diode. For proper operation, the inductor must be chosen so that its current does not change appreciably during the switching of the tunnel diode. The value of this inductance can be approximated by:

$$L = \frac{C}{I_p^2} \qquad (3)$$

where: I_p is the peak current in microamperes, C the diode capacity in picofarads, and L the inductance in henries. The tunnel rectifiers used for directionality are tunnel diodes with peak currents approximately two orders of magnitude lower than the tunnel diodes used for switching stages. Dissipation in the *or* gate is approximately 70 μW and in the *and* gate is 30 μW.

For storage in registers, the bistable circuit of Fig. 5 can be used. In this circuit, bistability is produced by the combination of the two tunnel diodes and a 400-mV bias. Dissipation in the low state is 24 μW and, in the high state, 97 μW. The bistable stage is set by application of a positive pulse from an *or* gate and reset by inverting a positive pulse through a transformer. Loads for the bistable circuit would consist of *and* gates, where a fixed load is supplied by the *and* gate when it is in the low state and the bistable is high. Under these conditions, reset can be accomplished with minimum current. Connections of these basic gates to form a shift register stage and counter stage are shown in Figs. 6 and 7.

To evaluate the performance of the circuits in the presence of wideband noise, tests were made on the *or* gate and these results compared with tests on a similar high speed circuit using tunnel diodes in the 50-μA range. These tests showed that the micropower circuits were as insensitive to noise as the high-speed circuits when properly shielded—because although the signal level at which the circuits operate has been reduced by a factor of 100, the bandwidth of the circuits has also been reduced by almost the same amount.

Table II compares the performance of present and extended micropower tunnel diode logic, with 300-Mc/s tunnel diode circuits.[8,9] Notice that the extended circuits operate at 1/100 the

Fig. 4—Constant-current biasing arrangement for monostable gates.

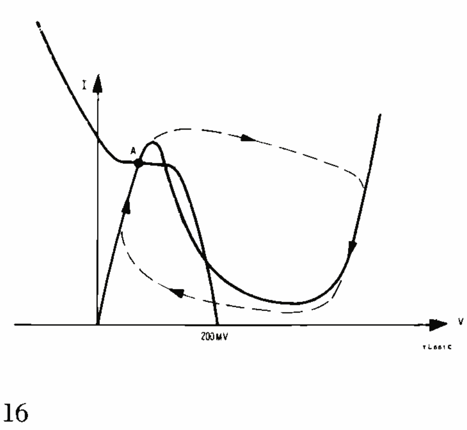


Fig. 5—Bistable stage.

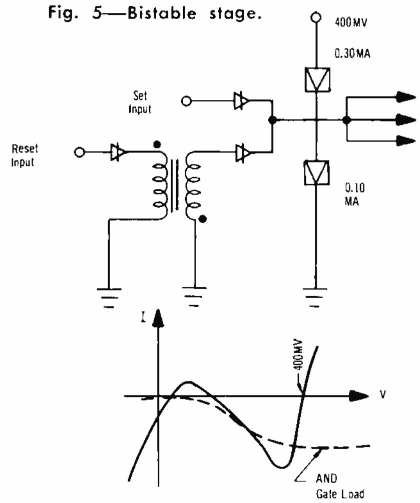


Fig. 6—Interconnection of "and" and "or" gates to form shift-register stage.

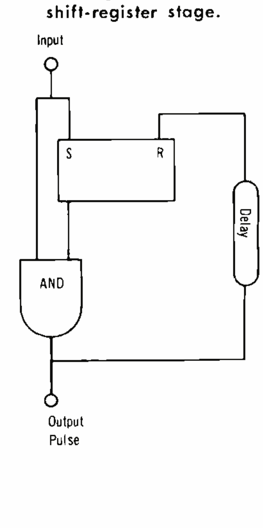
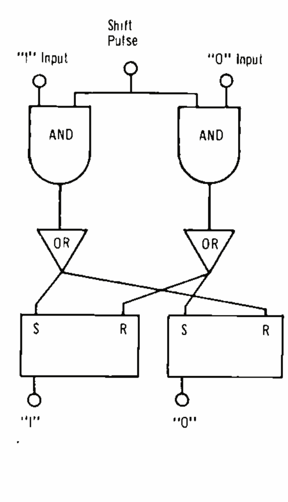
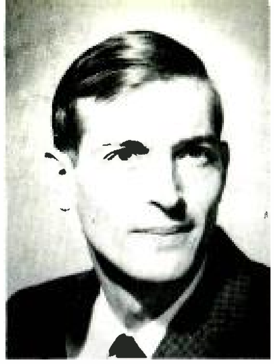


Fig. 7—Logic arrangement of counter stage.





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DR. RICHARD GLICKSMAN received the BS, MS, and PhD in Chemistry from N.Y.U. in 1948, 1949, and 1953, respectively. Dr. Glicksman joined RCA Laboratories to work on electrochemical phenomena until 1959. In 1959 he became Engineering Leader of the Vacuum Deposition and Chemical Thin Film Resistor Laboratory in the RCA Semiconductor and Materials Division. In 1961, he became Manager in the Computer Device Development group. Dr. Glicksman assumed his present position as Manager, Advanced Devices in 1963; he is in charge of the development of insulated-gate field-effect transistors, integrated diode arrays for memories, GaAs high-frequency power transistors, and high-current tunnel diodes and inverters. Dr. Glicksman holds 10 issued patents. He is a member of the Electrochemical Society, Sigma Xi, and Phi Lambda Upsilon. He has received an "RCA Laboratories Achievement Award." He is listed in "American Men of Science" and "Who's Who in Electronics."

R. H. BERGMAN received his BSEE from Rutgers University, New Brunswick, New Jersey, in 1953. He joined RCA in 1953, where he has worked primarily on pulse and digital circuitry, analog-to-digital conversion, ultrasonic measurements, and the application of tunnel diodes to computers. In 1960, Mr. Bergman was promoted to Leader, Design and Development Engineering, where he was responsible for logic-circuit work on a development project for a 1-gigacycle computer. He is currently with DEP Applied Research in Camden, where he is working on advanced computer development. Mr. Bergman is a member of Tau Beta Pi, and Eta Kappa Nu.

speeds of the 300-Mc/s circuits, yet dissipate only 1/6000 of the power. Further, at the very low power levels (3 to 7 μW), worst-case-design repetition rates of 3 Mc/s are possible.

There are several factors which determine the reduction of speed and power in the micropower circuits. Assuming circuit configuration and power supply values remain the same, then power reduction would scale linearly with the peak current of the tunnel diodes chosen. Additional power savings are possible, however, due to the ability to simplify the circuit configuration at lower operating speeds. The effect of stray inductances is not critical here, and a higher gain per stage can be obtained. In addition, current sources can be removed from the circuits further reducing standby power dissipation.

As an example of the drastic improvements which may be obtained with the extended circuits, Table III lists the power requirements for a small computer of 1,024-word memory and 16-bit word length. The total power for such a computer would be about 0.14 watts.

TABLE II—Comparison of Tunnel Diode Logic Gate Parameters

Type of Logic	*Present High-Speed Circuits (Individual Gates)*	*Micropower Circuits (Sum-of-Prod)*	*Extended Micropower Circuits (Sum-of-Prod)*
D.C. Power Dissipation Per Logic Level, mW	*and* 137 *or* 57	*and* 0.023-0.046* *or* 0.050*	0.003-0.007
D.C. Supply Voltages, mV	210-550	200 and 400	200 and 400
D.C. Current Drain, mA	25-80	0.2-0.4	0.02-0.04
Fan-out	*and* 3 *or* 6	3	3
Fan-in	*and* 6 *or* 5	6	6
Signal Levels, mV	400	300	300
Signal Voltage Risetimes, ns	0.2	15	20
Logic Circuit Delay, ns	0.5-1.0	25	30
Repetition rate, Mc/s	300	10	3
Resistor Tolerances, End-of-Life	±2%	±2%	±2%
Voltage Tolerance	±4%	±4%	±4%

*Total dissipation for a sum-of-products gate consisting of 3 *and*'s and 1 *or*, will average 0.160 mW.

TABLE III—Power Requirements For A Micropower Machine

	Quantity	*Average Unit Dissipation, μW*	*Total Power, μW*
Memory Cells	16,384	3.0	49.2
Word Switch and Drivers	1,024	55.6	57.0
Digit Drivers	128	29.5	3.8
Sense Amplifiers	512	2.5	1.3
Regeneration Register	150	—	9.3
Decoder	166	—	1.6
Arithmetic and Control Units	250 Bistable	6.0	
	750 Sum-of-Prod	19.0	15.4
			Total: 137.9 (~0.14 watts)

CONCLUSION

Tunnel-diode micropower logic circuits have been constructed and operated at 10-Mc/s repetition rate, dissipating 160 μW of power. Circuits appear feasible which will provide repetition rates of 3 Mc/s dissipating 3 to 7 μW of power. These circuits should be operable at irradiation doses of the order of 10^{16} nvt, and over temperature ranges of −20 to +70°C. Noise immunity of such circuits is also good due to the improved low pass filtering of the circuits.

By increasing the number of stages in a logic gate, the acceptable temperature range and irradiation dose may be increased. Speed can also be increased by increasing the power dissipation per stage.

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RESEARCH IN SUPERCONDUCTIVITY AT RCA LABORATORIES

RCA Laboratories has engaged in research in superconductivity since the early 1950's, requiring the combined talents of chemists, metallurgists, physicists, and electronics engineers. This integrated effort reflects not only the degree of sophistication encountered in the synthesis, characterization, and electronic behavior of superconducting materials, but also the emergence of superconducting devices involving cooperative phenomena and intricate techniques of fabrication. This paper surveys progress in this field in essentially chronogical order, including thin-film cryotrons and memories, BCS theory, Nb_3Sn and type II superconductivity, high-field Nb_3Sn magnets, and microwave amplification.

DR. F. D. ROSI

RCA Laboratories, Princeton, N. J.

DR. FRED D. ROSI received a BE in Metallurgy from Yale University in 1942, his ME degree in 1947, and a PhD degree in 1949 from the same institution. He was awarded the graduate laboratory assistantship in the Department of Metallurgy at Yale in 1946-49. Dr. Rosi engaged in fundamental research on mechanical properties and recrystallization phenomena in metals and alloys at Sylvania Electric from 1949 to 1954. In 1954, he joined RCA Labs. where he heads up the Semiconductors, Superconductors, and Metals Research section engaged in the preparation of elemental and compound semiconductor crystals for transistor and thermoelectric applications, and in research on superconductivity and electronically active organic materials. Dr. Rosi is a member of the Yale Engineering Society, the Yale Chapter of Sigma Xi, the American Institute of Metallurgical Engineers and the American Physical Society. He is currently a member of the NASA Research Advisory Committee on Materials the Semiconductor Committee of the AIME, and the Power Sources Committee of the IEEE. Dr. Rosi has more than 30 publications to his credit and 13 filed patents relating to the preparation of semiconductor, thermoelectric, and superconductor materials, and device fabrication. He received a 1955 RCA Achievement Award for "major improvements in the techniques of growing semiconductor crystals useful in transistors." In 1963 he was one of the recipients of the David Sarnoff Outstanding Team Award in Science.

MUCH of our modern technology is based upon old principles that have been reinterpreted in the light of new theories, and re-examined with new materials. A few examples are the electron-hole concepts in semiconductor devices; electron excitation and radiation in luminescent screens; and the direct conversion of heat or light into electrical energy by thermoelectric, thermionic, and photovoltaic techniques.

The same is true of superconductivity and its applications, a branch of the physical sciences that has a long tradition. It dates back to the liquification of helium in 1908 by the Dutch physicist Kammerlingh Onnes[1], and his discovery three years later that the electrical resistance of mercury abruptly vanished at temperatures a few degrees above absolute zero, in contradiction to the classical theories of electrical conduction in solids. Thus, a current induced in such a metal at these low temperatures would flow endlessly without further input of energy—hence the terminology, *persistent current.*

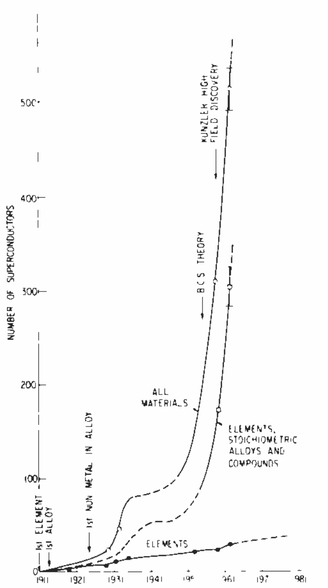

Fig. 1—Approximate growth of knowledge of superconductive materials during the last 50 years (Ref. 9).

PIONEERING WORK

The early pioneering work of Onnes and the studies of Meissner[2] in the 1930's formed the basis for characterizing superconductors, at least from a gross experimental standpoint. Below a critical temperature T_c called the *transition temperature*, these characteristics are: 1) zero electrical resistance for direct current flow, 2) almost perfect diamagnetism with ability to exclude or confine a magnetic field, except for a very small but important penetration at the material surface (the *penetration depth*), and 3) the ability to revert from the superconducting state of zero resistance to a normal resistive state in the presence of a sufficiently large magnetic field that can be applied externally or generated directly by current flow (the *critical field*, H_c).

In spite of these fascinating properties, the phenomenon of superconductivity remained largely a matter of academic curiosity for nearly forty years. This seems particularly strange when one considers that during this period such applications as superconducting magnets (Onnes, 1913)[3] and superconducting switching elements (Casimir-Jonker and de Haas, 1935)[4] had already been proposed. However, this picture changed dramatically in the past decade with advances in materials exploration (Matthias, 1945)[5], cryogenic computer technology (Buck, 1956)[6], microscopic theory (Bardeen, Cooper and Schrieffer, 1957)[7], and high-field studies (Kunzler, 1961)[8]. Researchers were now provided with a better understanding of fundamental effects, new materials with broader properties, and an increased awareness of the possibilities for exploiting the properties of superconductors in a host of new electronic applications.

While superconductivity was little more than a scientific oddity 20 years ago, today it is the subject of intensive investigation by scientists of all disciplines in solid state research; Fig. 1 shows an almost exponential increase in the number of known superconductors over the period, 1950-1962. It is even more remarkable that in the two

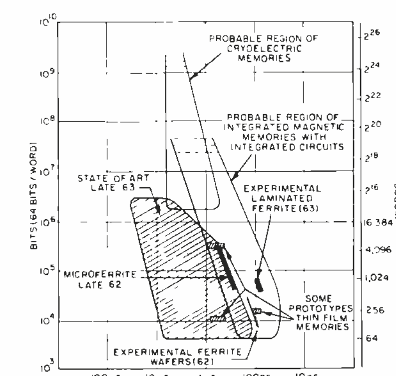

Fig. 2—Storage capacity and cycle time of various memories (Ref. 10).

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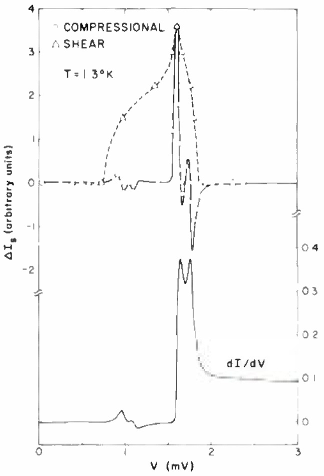


Fig. 3—Typical bias dependence of the current pulses, ΔI_s, due to compressional and shear waves, obtained with Al-Pb tunnel diodes. The first derivative of the current-voltage characteristics in the absence of sound waves is also shown.

years since this survey was made by Roberts,[9] the number of superconductors has increased to over 900. It is also apparent from Fig. 1 that with this resurgence of interest in superconductivity the spectrum of materials research in electronics now included metals, metal alloys, and intermetallic compounds which heretofore were considered to be electronically "passive."

THIN FILM CRYOTRONS AND MEMORIES

Research in superconductivity at RCA Laboratories was first stimulated by the early work on superconducting-normal switching phenomena, and the ability of a superconducting loop to store a persistent current. Further impetus was given by the application of this basic information to the design of cryoelectric switching elements (cryotrons) by Buck[8] for computer logic and memory circuits.

The thin-film cryotron, as well as cryoelectric memory elements, incorporate all of the basic features of superconductivity: namely, the sharp transition between the normal and superconducting states, the ability to control the transition with magnetic fields, and the ability to support persistent currents and confine magnetic fields. These varied properties of the superconductor, in addition to the inherently small size and microscopic power consumption of such devices, have provided computer components with potential advantages in combined storage and speed of handling information that would be difficult to realize through any other existing, or even contemplated technology. This is indicated in Fig. 2, where storage capacity in bits is plotted against cycle or information access time for various memory devices.[10] It may be seen that with cryoelectric memories, one can reasonably expect a storage capacity of 10^7 to 10^9 bits with a respectable cycle time of 1 to 10 μs. However, to achieve such performance is no longer solely a matter of proposing new schemes for building such cryogenic devices, or devising a greater variety of circuits capable of performing certain logical operations. There are also needed new techniques of depositing thin films of superconductors in microdimensional networks which can be infinitely complex, as well as a better understanding of the conditions which govern the kinetics of the superconducting-normal transition when in a circuit environment. A step forward in this technology was very recently made by a group of scientists at the RCA Laboratories under the supervision of L. L. Burns. They designed and constructed a continuous plane memory[11] which is a distributed version of discrete memory elements containing 16,384 bits on a 2-by-2-inch substrate, with a cycle time of 2 to 3 μs. However, as promising as this memory device appears, it is still a long way from being practical, particularly with regard to reproducibility from cell to cell or plane to plane. In fact, this device emphasizes what has already become a familiar tune to the materials scientist in electronics: higher-quality materials, better synthesis techniques, and characterization on a more sophisticated level: and these criteria must be met if one is to advance cryoelectric computer technology.

Fig. 5—Vapor-deposited Nb_3Sn on the inside of a ceramic cylinder.

THE BCS THEORY

A second advance that motivated research in superconductivity at RCA Laboratories was the so-called *BCS theory*—a theoretical interpretation of superconductivity in 1957 by Bardeen, Cooper, and Schrieffer.[7] Two features of the BCS theory offered challenges to the materials scientist: *First*, the explicit expression for the transition temperature suggested the possibility of finding materials with transition temperatures in the vicinity of their Debye temperature. In addition, materials parameters such as electron density of states and phonon-electron interaction potentials could now be added to the empirical electron-to-atom ratio rules of Matthias in the search for new superconductors. *Second*, the BCS theory associated the energy change of an electron in going from the normal to the superconducting state with an

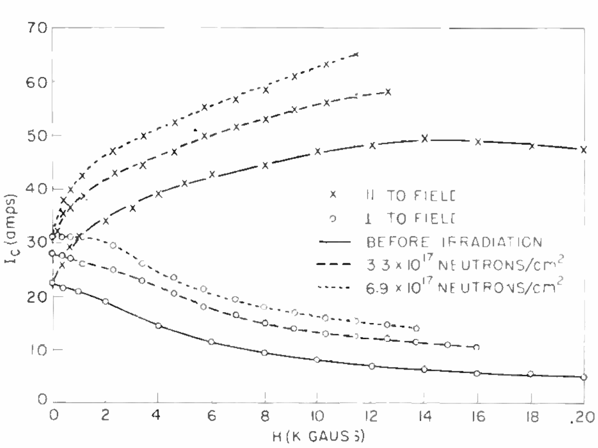
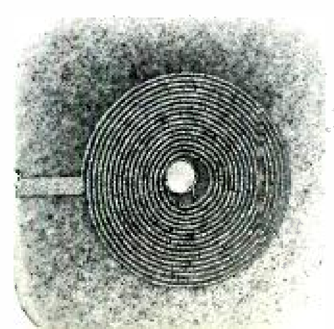


Fig. 4—Current-carrying characteristics of Nb_3Sn specimen before and after neutron irradiation.

Fig. 6—Polished Nb_3Sn and a spiral of Nb_3Sn on ceramic substrates.



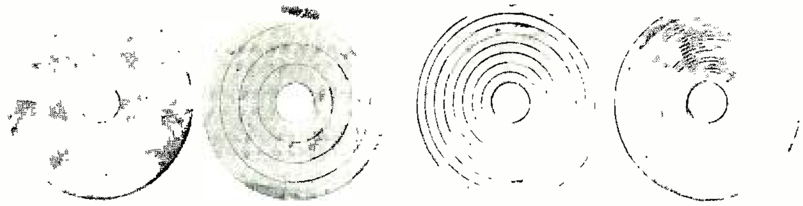


Fig. 7—Vapor-deposited Nb_3Sn films on platinum foil (1-, 4-, 8- and 20-ring discs).

energy gap of the order of 3.5 kT_c, where k is Boltzmann's constant and T_c is the transition temperature. This concept suggested to investigators a normal-to-superconducting transition time in the range of 10^{-9} to 10^{-12} seconds, as well as phenomena such as tunneling (Giaever, 1960)[12] and carrier injection across superconducting junctions analogous to that across p-n junctions in semiconductors. In addition, phonons, which heretofore were considered undesirables as noisemakers impeding electron flow in semiconductors and as wasteful nuisances in dissipating energy as heat in phosphor materials, were now playing a useful role as catalysts in the conversion of normal, uncorrelated electrons to superconducting, correlated electrons.

These new phenomenological twists resulting from the BCS energy-gap concept hold great promise for developing a new generation of cryogenic devices based on quantum tunneling effects, as well as phonon-assisted transport processes. Already, superconducting diodes are being considered for development as a cheap low-power-dissipation amplifier, and microwave phonon energy has been used to effect the current-voltage characteristics of such diodes. Fig. 3 shows very recent data, obtained by Abeles and Goldstein[13] at the RCA Laboratories, on tunneling between superconductors induced by transverse and longitudinal microwave phonons. The coherent sound waves give rise to an extra tunneling current ΔI_s which depends strongly on the voltage bias V across the tunnel diode. The ΔI_s due to longitudinal phonons *(compressional waves)* show a totally different behavior than ΔI_s for transverse phonons *(shear waves)*. Also shown in Fig. 3 is the derivative (dI/dV) of the current-voltage characteristic in the absence of the sound waves. To the best of our knowledge, the data in Fig. 3 are the first of their kind to be observed; and the strong dependence of ΔI_s on V suggests that these diodes could be good microwave sound detectors. If nothing else, these early device attempts, based on the existence of an energy gap in superconductors at low temperatures, served to classify these materials as truly electronically active. In fact, the synthesis of a superconducting semiconductor has now been achieved[14]—which only a short time ago would have been considered a ridiculous thought.

NIOBIUM STANNIDE (Nb_3Sn) AND TYPE II SUPERCONDUCTIVITY

At the start of our search for new superconductors in 1957, it seemed logical to investigate first the compound superconductor, niobium stannide (Nb_3Sn). This compound had the highest known transition temperature (18.3°K), and represented an excellent prototype of the then ill-defined, hard (type II) superconductors with the β-tungsten structure, and all with relatively high transition temperatures. As our research (as well as that in many other laboratories) progressed, it became even more apparent that a concentrated effort on the superconducting properties of this particular material could be more fruitful than undertaking a broad sweep of this multifaceted area of research. This decision was influenced to a large extent by: 1) the development at RCA Laboratories of a vapor-phase transport technique for preparing Nb_3Sn by Hanak[15] in 1960;

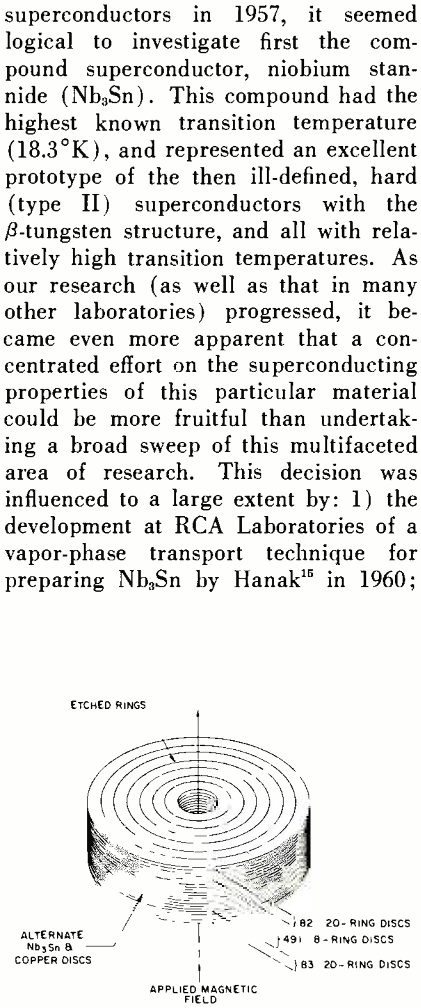
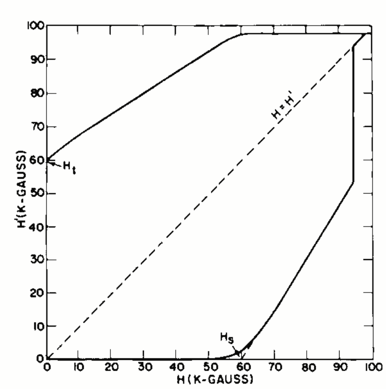


Fig. 8—(a) Stacking of Nb_3Sn discs and copper discs in a 60-kilogauss Nb_3Sn permanent magnet. (b) Applied field H vs internal field H' for the 60-kilogauss Nb_3Sn magnet.



and 2) the high current-field studies of Kunzler[8] at Bell Telephone Laboratories published in 1961, which clearly indicated the possibility of constructing high-field (at least up to 88 kilogauss) electromagnets with Nb_3Sn with virtually no power dissipation.

The RCA vapor-phase synthesis technique involved the simultaneous reduction of the respective chlorides of the constituent elements, niobium and tin, with hydrogen on a properly heated (900 to 1200°C) substrate. This growth technique became the predominant factor in formulating our experimental research program in type II superconductivity. There were several good reasons for this:

First, it was possible to prepare—for the first time—Nb_3Sn in single-phase massive crystalline forms with theoretical density, high purity, and controlled chemical composition and grain structure; and this well-characterized material should be contrasted with the multiphase, porous and highly brittle product obtained by metallurgical sintering techniques. Moreover, the vapor-phase technique also lent itself to the growth of single crystals, such as "whiskers", of high structural perfection. These aspects of materials preparation were desirable prerequisites for a definitive examination of the role of lattice defects such as vacancies, dislocations, and structural order-disorder on superconducting properties and, in particular, on the validity of the mixed state concept advanced by Abrikosov[16] in 1957 to explain the high critical magnetic field characteristics of type II superconductors. An example is the recent study of neutron irradiation on the current-carrying behavior of Nb_3Sn by Cullen, Novak, and McEvoy[17] at the RCA Laboratories using the Industrial Reactor facilities at Plainsboro, N.J. One aspect of this work is given in Fig. 4, which shows the variation in critical current I_c with applied magnetic field H for vapor-deposited Nb_3Sn before and after irradiation with neutrons. It may be seen that neutron-induced defects (called *dislocations*) significantly increase the critical current over the entire range of magnetic field studies, regardless of whether the current is parallel or perpendicular to the field. In accrodance with the Abrikosov theory,[16] the higher values of I_c with neutron irradiation can be directly attributed to the ability of dislocations to impede the motion of flux filaments (called *fluxoids*) through the Nb_3Sn under the impetus of a Lorentz force I_cH which would otherwise destroy its superconductivity and current carrying capacity.

A second feature of the vapor-phase growth technique responsible for governing our experimental program was the ability to deposit single-phase Nb_3Sn on both metallic and ceramic substrates in various configurations including planar and cylindrical geometries. Examples of this versatility are given in Figs. 5 and 6 by the deposits of Nb_3Sn on ceramic steatite (magnesium silicate) substrates taken from the work of Cullen.[18] Fig. 5 shows an Nb_3Sn film on the inner surface of a cylinder, while Fig. 6 shows highly polished and spiral deposits of Nb_3Sn on flat steatite substrates. With such specimens, researchers at the RCA Laboratories were able to carry out experiments on the basic properties of Nb_3Sn, which were heretofore not possible or could not be done in a definitive manner. With Nb_3Sn on metallic wire substrates, Cody[19] measured for the first time the superconducting penetration depth of Nb_3Sn ($\sim$3,000 angstroms) which supports the most recent theories of type II superconductors.[20] It was also possible on metallic substrates to measure the flux shielding and trapping characteristics of Nb_3Sn when prepared in complex film patterns, such as those shown in Fig. 7. Here, one sees vapor-deposited Nb_3Sn films (0.1 mil thick) on platinum foil discs (0.5 mil thick, 1 inch diameter) in a pattern of 1, 4, 8, and 20 concentric rings around a punched hole (0.2 inch diameter). Magnetization studies by Hanak[21] showed that with the 8-ring-geometry discs it was possible to trap or shield magnetic fields of record strengths up to 60 kilogauss at 4.2°K. This basic work led to the construction of a 1-inch-long Nb_3Sn permanent magnet of 60 kilogauss by stacking 491 of the 8-ring discs and 165 of the 20-ring discs, interleaved with copper discs for stability, as schematically illustrated in Fig. 8. The magnetization hysteresis curve for this magnet is also given in Fig. 8, which shows that the Nb_3Sn-Pt disc structure is also capable of shielding (H_s) as well as trapping (H_t) the 60-kilogauss field. The initial *magnetic charging* (application of external field H) of this superconducting magnet was accomplished by using the magnet facilities of the Bell Telephone Laboratories; and, on removal of the Nb_3Sn magnet from the BTL facility, the 60-kilogauss trapped field remained constant as long as the magnet structure was kept at 4.2°K. Hence, this superconducting permanent magnet requires no external power supply and is portable.

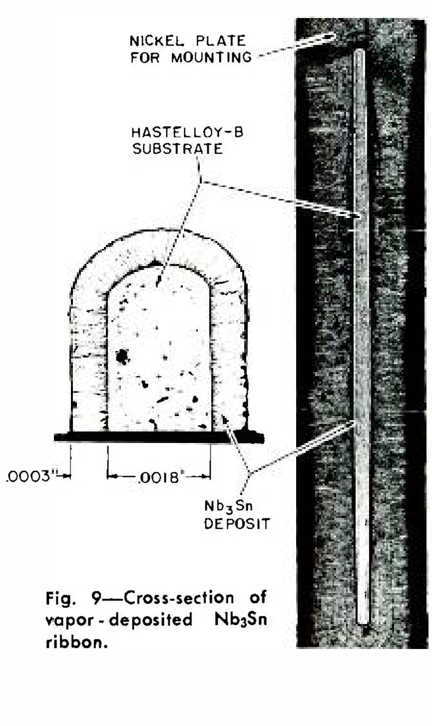


Fig. 9—Cross-section of vapor-deposited Nb_3Sn ribbon.

The ability to deposit Nb_3Sn on insulating substrates is desirable in superconducting research for a number of reasons: the substrate does not interact with applied or induced currents and fields; diffusion of metallic impurities into the Nb_3Sn is avoided, both during specimen preparation and heat treatments; particle irradiated samples are not more active than the superconducting deposit; and unsupported superconducting films can be prepared by preferential chemical dissolution of the insulating substrate. Definitive studies at RCA Laboratories made possible with Nb_3Sn films on insulating ceramic substrates, such as those in Figs. 5 and 6, included:

1) the determination of the BCS energy bandgap of Nb_3Sn by both tunneling (Goldstein) and themal conductivity measurements (Cody and Cohen)
2) tube magnetization experiments of critical-state phenomena and flux jumping (McEvoy)
3) the dependence of normal resistance on temperature (Woodard and Cody)
4) critical-field determination by mircrowave surface impedance (Rosenblum, Cardona, and Fischer)
5) angular dependence of current and field on the current-carrying properties of Nb_3Sn (Cody and Cullen)
6) the neutron irradiation effects alluded to earlier (see Fig. 4)

The knowledge derived from these basic studies has greatly enhanced our understanding of the superconducting behavior of Nb_3Sn and of type II superconductors, in general; and such knowledge was instrumental in the fabrication of high field Nb_3Sn solenoid magnets, as well as in establishing the field limits of such magnets. Detailed accounts of all the above basic studies can be found in a special issue of the *RCA Review*,[22] which contains twenty papers devoted to the synthesis, characterization, and application of Nb_3Sn.

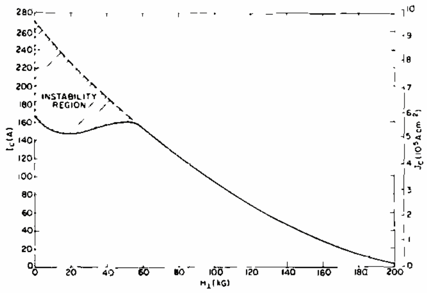


Fig. 10—Current carrying characteristics of a typical vapor-deposited Nb_3Sn ribbon (current density J_c pertains to the Nb_3Sn deposit).

HIGH FIELD Nb_3Sn ELECTROMAGNETS

A most important feature of the RCA vapor transport technique was its adaptability to the continuous deposition of Nb_3Sn on a flexible metal ribbon substrate with high mechanical strength.[22] The ability to produce such Nb_3Sn ribbon was essential for magnet windings in high-field superconducting solenoids; and the inherent brittleness of Nb_3Sn precluded the use of unsupported material for the windings. With apparatus developed by the Superconductor Materials and Devices Laboratory of the RCA Special Electronic Components Division, ribbon lengths up to 1 km could be readily produced. A cross-sectional view of this ribbon is given in Fig. 9, which shows a 0.00076-cm deposit of Nb_3Sn on a 0.0046-cm-thick nickel-base alloy (Hastelloy) substrate. Hastelloy was selected as a substrate material for two reasons: 1) it has a reasonable match in thermal coefficient of expansion with Nb_3Sn; and 2) it provides the ribbon with high mechanical strength (150,000 psi at 4.2°K), which is necessary to contain the stresses generated by the high magnetic fields in a solenoid en-

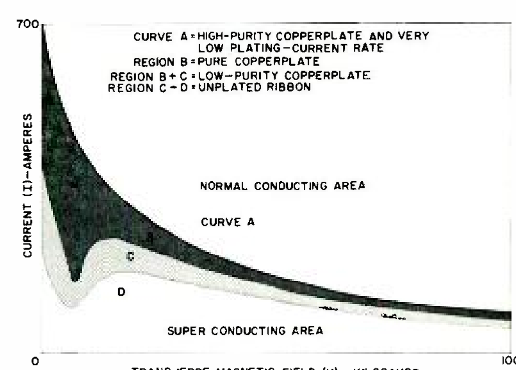


Fig. 11—Stabilizing effect of copper plating on inherently unstoble Nb_3Sn ribbon.

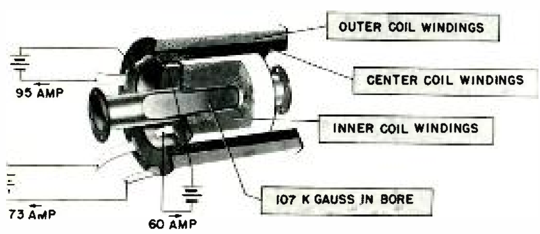


Fig. 12—RCA 107-kilogauss Nb_3Sn solenoid.

vironment. The curve of current density vs. field in Fig. 10 shows that this ribbon can supply current densities in the Nb_3Sn deposit as high as 2×10^5 amperes/cm^2 at a field strength of 120 kilogauss, and can still support sizeable currents near 200 kilogauss.

At low magnetic fields, the Nb_3Sn ribbon usually exhibits current degradation (shaded region in Fig. 10), which is attributed to instabilities in the Nb_3Sn deposit associated with the motion of flux bundles through the superconductor. Schrader and Kolondra[22] of the RCA Special Electronic Components Division analyzed this degradation effect, and found it to be more pronounced for ribbon in a coil form than as short segments. In addition, it was possible to modify the degradation by changing process variables during ribbon fabrication, and by plating the ribbon with a good electrical and heat conductor such as copper or silver. The effect of copper-plating short samples of Nb_3Sn ribbon on critical current vs. field characteristics is summarized in Fig. 11, taken from the work of Schindler and Nyman.[22] It may be seen that the copper-plated ribbon not only provides a higher critical current for a given field, but also narrows the region of current instability with respect to magnetic field; and under ideal plating conditions, upper solid curve, the current degradation can actually be eliminated. There are two possible explanations for the improvements in I_c and current instability due to copper plating:

1) the eddy currents generated in the copper plate could distribute the magnetic field more uniformly along the superconductor, thereby reducing the size of flux filaments penetrating the superconductor and, hence, the amount of energy released during their movements
2) the copper, being a good thermal conductor as compared to liquid helium, can be very effective in dissipating the heat energy associated with the motion of flux bundles through the superconductor.

With knowledge derived from data (such as that shown in Fig. 11) on many tests of Nb_3Sn ribbon in coil form, members of the engineering staff of the Special Electronic Components Division under the direction of N. S. Freedman designed and constructed a 107-kilogauss solenoid magnet with a working space, 1 inch in diameter and 3.5 inches long, and operating at liquid-helium temperature (4.2°K). This magnet (Fig. 12) is the highest field superconducting magnet ever built for its size (working bore). Its external dimensions are approximately 6 inches in diameter and 5.5 inches long, and it is powered by three 6-volt batteries. (Very recently at Brookhaven National Laboratories, a 112-kilogauss magnet was constructed with a 1⅛-inch-diameter bore using RCA Nb_3Sn ribbon.)

By contrast, nonsuperconducting magnets require almost 1.5 million watts of power and enormous cooling systems to achieve similar magnetic fields. The 107-kilogauss magnet was designed in the form of three separate coils, each separately energized from twelve separate lengths of silver-plated Nb_3Sn ribbon totaling 4,440 meters. Fig. 13 shows the composite *I-H* loading curves for the three coils to produce the 107 kilogauss. The shaded areas indicate the range of critical values obtained in small sample test coils. The 30 kilogauss obtained with the outside coil clearly reflects current degradation, while the fields achieved by the center and inner coils correspond to sample test data.

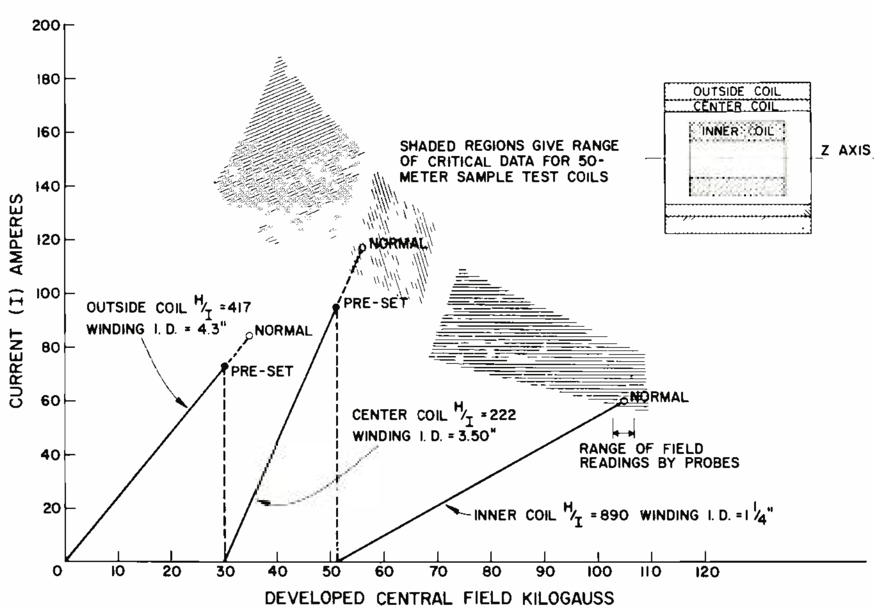


Fig. 13—Critical (and preset) fields and currents for each of three axially aligned coils yielding 107-kilogauss central field in 1-inch bore.

The availability of high-field superconducting magnets is expected to enable more widespread basic research in solids, liquids, and gases—now limited to a few laboratories because of the multimillion dollar facilities required to generate such immense magnetic fields. Research now going on in many broad fields of physics—such as nuclear magnetic resonance, Mössbauer effect, Zeeman splitting, Faraday rotation, de Haas—van Alphen experiments, magneto-tunneling, magneto-optical and thermomagnetic effects—could proceed into higher magnetic fields and in many more laboratories.

Superconductive magnets with negligible power input could be a key factor in attaining economic feasibility for new energy-conversion techniques, such as magnetohydrodynamics (MHD) and thermonuclear energy, which require large volume intense magnetic fields for efficient power production. Similarly, such large-size, high-field magnets would provide the means to expand research in the important field of high-energy particle physics.

Space exploration will also receive major benefits from superconductive magnets. In bores of 1 to 2 feet, superconductive magnets could someday shape the plasmas of jet propulsion engines for long-distance space travel of manned space vehicles. Still larger-bore, high-field magnets are proposed as an electromagnetic safety shield from dangerous high-energy space particles for interplanetary travel. In this application, a superconducting magnet would be designed to encircle a space ship completely with an intense magnetic field. Fields approaching 150 kilogauss, for example, would deflect from the space vehicle extremely hazardous high-energy protons emanating from solar flares. Magnet size for this active shielding application would necessarily be many feet in diameter, and would require considerable improvements in superconducting materials performance and design.

MICROWAVE AMPLIFIER

Although research in superconductivity has been directed largely towards possible applications in computers and high-field magnets, superconductivity has also been put to work very recently by Clorfeine and Hughes[23] at the RCA Laboratories in developing a microwave amplifier (Fig. 14). In this device, the first of its kind, use is made of a nonlinear inductance and frequency conversion in type I superconducting films at frequencies extending well into the millimeter-wave range.

The amplifier consists essentially of a sandwich arrangement of crystalline cubes of quartz and rutile separated by a thin film of tin. The quartz serves as a heat sink, while the rutile represents a low-loss, high-permittivity dielectric resonator. When this structure is placed inside a waveguide and then immersed in liquid helium, the superconducting thin film will interact with certain microwave frequencies causing amplification. This device has been operated at 6 Gc/s, where it has produced a net gain of 11 dB with a pump frequency slightly less than that of the signal. The pump power required for amplification was only 0.2 μW, which is orders of magnitude less than that for varacators. This unusually low power requirement is partially due to the very small loss factor of the superconductor.

Fig. 15 shows the output and the input spectra of the amplifier. The lower trace shows pump and signal inputs of −37 dBm and −65 dBm, respectively. The upper trace is device output and illustrates a larger signal, a reduced pump, and three new frequencies which result from the mixing processes in the superconducting film. With the signal input turned off and the pump parameters properly adjusted, parametric oscillations were also observed. As expected, these occurred in pairs symmetrically spaced about the pump frequency.

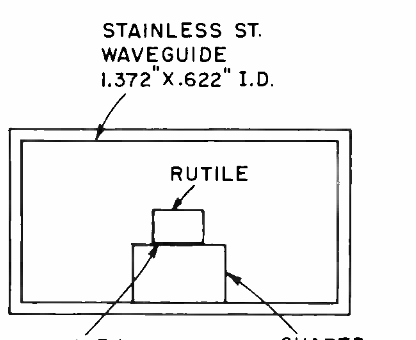


Fig. 14—Superconducting parametric amplifier (Ref. 23).

This superconducting paramp offers several outstanding features not to be found in the varactor, or any other device: First, the frequency limit of superconducting films may extend into the sub-millimeter wave range. Second, the noise performance of this device is expected to match that of the maser; and in addition, considerably less power is required to pump this superconducting device as compared to the maser or varactor. Finally, since large area superconducting films can be prepared, then wideband, truly-distributed traveling-wave parametric amplification is possible.

SUMMARY

Recent research in superconductivity at RCA Laboratories has involved the synthesis, characterization, and application of superconductors; and, as such, exemplifies the spectrum of research encountered in the electronics industry. Particularly noteworthy the research on niobium stannide (Nb_3Sn) and its application to high-field magnets underscores the importance of novel materials synthesis techniques not only in the search for new knowledge, but also in the practical utilization of this knowledge.

The current research activity in superconductivity has already led to a better understanding of both types I and II superconductors, and the application of these materials to laboratory models of high-field magnets, compact computer memories, and solid-state amplifiers. However, this progress represents only the early stages of a rapidly advancing technology which could have a major impact on the electronics industry, much like that experienced with the advent of the transistor and semiconductor technology 20 years ago.

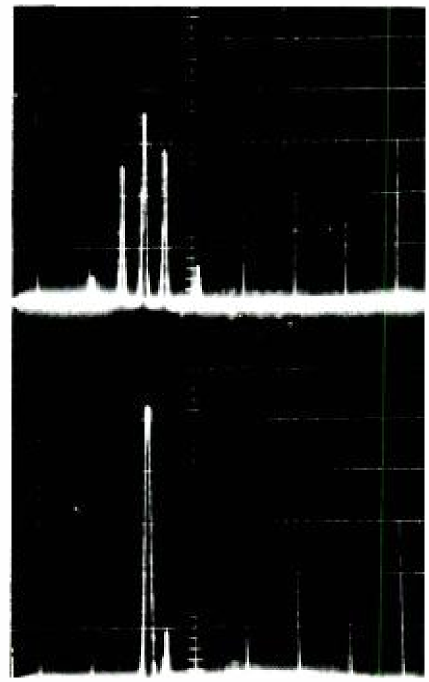


Fig. 15—Output and input spectra of the superconducting parametric amplifier (Ref. 23).

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HIGH-FREQUENCY SUNSPOT DISTURBANCE FORECASTING BASED ON PLANET POSITIONS

JOHN H. NELSON joined RCA Communications in October, 1923 after three years service with the Commercial Cable Co. as a student and cable operator. Between 1923 and 1946 he successively held the positions of operator, chief operator, traffic chief and supervisor. In 1946 he was transferred to Solar and Ionospheric research. Since that time his chief duties at RCA Communications, Inc. have been research, frequency predictions, and forecasting. Mr. Nelson is a Commander in the United States Naval Reserve.

The sun's five slow planets are in some manner associated with long term changes in sunspot numbers when in certain discrete angular relationships. A knowledge of sunspot activity related to planetary angular relationships can be used to forecast specific periods of high-frequency radio disturbances. Using this hypothesis, the author forecasts a significant increase in sunspot activity for July through December 1965, with the most severe disturbances probably between September 1 and 12, 1965.

J. H. NELSON

Propagation Analyst

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

In 1946, RCA Communications, Inc. established an Observatory facility with a 6-inch refracting telescope and suitable housing for the instrument on the roof of the 12-story Central Telegraph Office at 66 Broad Street, N.Y.C., for the study of sunspots and their possible connection with the behavior of high-frequency radio signals. They also, at that time, created the position of *Propagation Analyst* and assigned the author to this project due to his knowledge in the fields of both radio propagation and astronomy. After about three years research devoted to sunspots and concomitant high frequency signal behavior, it was concluded that an understanding of natural phenomena other than sunspots was necessary in order to provide the industry with forecasts of sufficient accuracy to be of value.

As explained in previous papers,[1-4] the position of the planets and their angular separation on a day to day basis was researched for a five year period in the past to determine if certain planetary angular relationships would coincide with high frequency radio disturbances.

The technique used for the determination of the heliocentric angular separation of the planets as they circle the sun was described in detail in Refs. 1 and 2. Briefly, the heliocentric (Sun-center) position of each of the sun's nine planets can be found in the *American Ephemeris and Nautical Almanac* published by the United States Government Printing Office, Washington 25, D.C. The angular separation of each of the planets from any other planet can be calculated from the information given in this publication. This five-year research project showed that there was useful co-relation between certain discrete planetary arrangements and the behavior of high frequency signals (3 to 30 Mc/s). The angular separations that were found to be the most important were; 0°, 90°, 180° and 270°. In the early 1950's, this planetary position technique was combined with sunspot observation techniques and resulted in a considerable improvement in forecasting; enabling an average accuracy of around 90% in daily forecasts for several years. Since 1950, improvements have been made in the technique and it has been found that harmonics of these major angulars also had to be considered. The base harmonic found to be of importance was 15° in multiples thereof all the way to 360°. Mercury, Venus, Earth and Mars were considered to be the fast planets; and Jupiter, Saturn, Uranus, Neptune and Pluto were considered to be the slow planets. When Mercury came to a position where it was 90° from Venus while Venus was 180° from Jupiter a radio disturbance would often develop if these three planets were at the same time related to two or three other planets at angles that were multiples of 15°. The planet Venus can be replaced by Earth or Mars in a combination of this sort with the same results. Jupiter, of course, can be replaced by some other slow planet. This is known as a multiple configuration with harmonics. It is the most important.

This type of research also indicated that significant changes in sunspot numbers would sometimes take place simultaneously with the significant planetary arrangement and this led the author to conduct research on sunspot numbers and planetary inter-relationships. A paper on these results was published[3] in 1962.

Since that time, further research has been conducted on this subject and sufficient information has been gathered to indicate that planetary arrangements quite definitely are associated with variations in sunspot numbers. Attention has been devoted more to the long term sunspot number variations rather than the short term fluctuations and it has been revealed that the sun's five slow planets from Jupiter to Pluto are in some manner associated with these long term changes; with the 0°, 90° and 180°, 270° separations again showing the greatest significance along with subsequent harmonics.

None of the sun's nine planets has a perfectly circular orbit. If such were the case, it would be a simple matter to determine cyclic harmonics between three or more planets. However, since each of the planets, as it leaves or approaches perihelion, is changing speed gradually, either slowing down or speeding up each day, it has not been possible to isolate any definite cyclic phenomena involving three or more planets. In certain parts of some particular planet's orbit however, it can be of such a velocity that it becomes possible for two other slow planets to become reasonably well synchronized with it. For the past 20 years there has existed a fairly close synchronization between the planets Jupiter, Saturn and Pluto which has not yet broken up, but which will probably break up in another decade or two. This particular arrangement of planets seems to coincide fairly well with major changes in sunspot numbers when all three be-

Final manuscript received February 22, 1965.

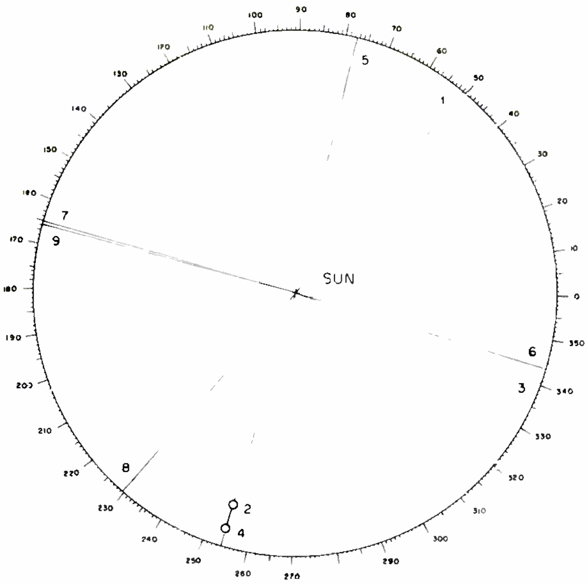

Fig. 1

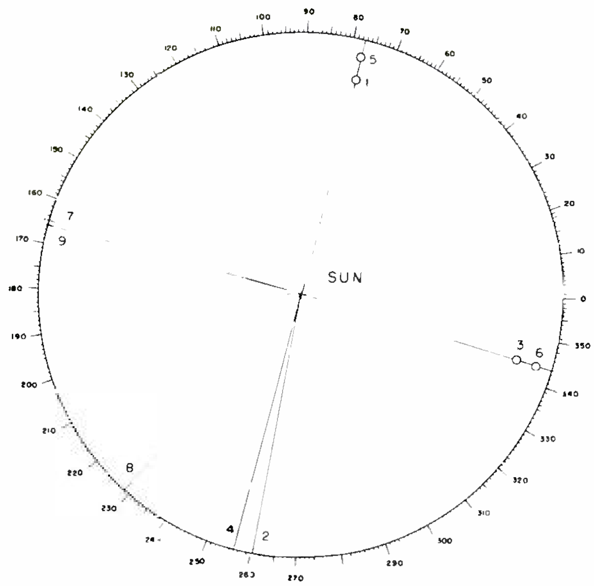

Fig. 2

Fig. 1 — Heliocentric (Sun Center) position of the planets at 0000 GMT September 3, 1965 showing multiple configurations of 0-90-180-270°.

Fast	*Slow*
1. Mercury	5. Jupiter
2. Venus	6. Saturn
3. Earth	7. Uranus
4. Mars	8. Neptune
	9. Pluto

Fig. 2—Heliocentric position of the planets at 0000 GMT Sept. 7, 1965. Continuation of Sept. 3rd multiple. This major multiple ends at 0000 GMT Sept. 12th with 3 being 90° ahead of 4.

come harmonically related during a relatively short period of time.

Earlier papers on this research identified "multiple configurations" of planets as those in which three or more planets become significantly related in a relatively brief period of time. In the case of two fast planets and one slow planet, this sometimes takes place in a few hours. In the case of three slow planets, a multiple is considered to exist if the three planets execute the configuration in a few months to a year.

Between June 1946 and August 1947 a multiple took place between Jupiter, Saturn, and Pluto. It was accompanied by a general rise from a monthly sunspot number of 80 at the beginning to a sunspot number of 180 at the end, dropping to 115 by December 1947.

No other multiples between these three planets took place until February 1956, when all three planets executed the multiple within one month. This was accompanied by a great burst of sunspots with the sunspot number increasing from 25 on February 10 to 260 by February 20, and dropping to 130 at the end of the month.

The next multiple between these three planets after 1956 will take place between July and December 1965. The planet Uranus will also come into this configuration because it will be only about 1° from Pluto at the time. Therefore, there will also exist a multiple between Jupiter, Saturn, and Uranus during the same period.

Major bursts of sunspots are forecast to develop between July and December under this configuration of planets. Uranus and Pluto will be 0° apart in 1966. Such a contact between Uranus and Pluto has not existed during the period covered by this research so any effect it will have is not known.

Figs. 1 and 2 show the position of all the planets for September 3 and September 7, 1965. The multiples between the four fast planets combined with the multiple between the four identified slow planets may well result in a major burst of sunspot activity accompanied by several solar flares and magnetic storms between September 1 and 12 with periodic interruption on long distance high frequency radio circuits. It is probable that this will be the most severe disturbance in the six months period.

It has been well known for over 100 years that sunspot cycles rise rapidly to a peak and drop off slowly to a minimum. The author has noted that an apparent explanation for this rapid rise may be due to the fact that the sun, being gaseous, does not rotate as a solid body, but rotates faster near the equator than it does in high latitudes. The rotation period is approximately 27 days near the equator but increases to as much as 33 days at 45° latitude. Therefore, since the characteristic of the first spots of a new cycle is that they are born in the higher latitudes, it is a simple matter to see that these high latitude sunspots are going to be counted for one or two more days than a sunspot near the equator. This results in a rapidly rising sunspot number graph at the beginning of a new cycle. This characteristic of the sunspot cycle exposes our ionosphere to prolonged periods of ionization resulting in a rapid rise also in useful communication frequencies.

CONCLUSION

It has been established beyond controversy that the number of spots on the sun and the best communication frequencies on long haul radio circuits are co-variants. It has also been well established that circuit reliabilities are higher with high sunspot numbers. It is therefore of prime importance to the HF communication industry to anticipate the future. Using the techniques described in this paper it is possible for a trained analyst to forecast major changes in sunspot activity and day to day variations in high frequency radio signal quality.

It is to this end-result that the author has conducted 15 years of applied research. Statistical researchers study solar-ionospheric effects to anticipate changes. Bringing the planets into the program may well lead us to the causes.

No theory has as yet been formulated that would explain the observed effects. There might possibly be some link, however, to electromagnetic interaction between the "planetary tails" that have been observed[5] by the satellite IMP.

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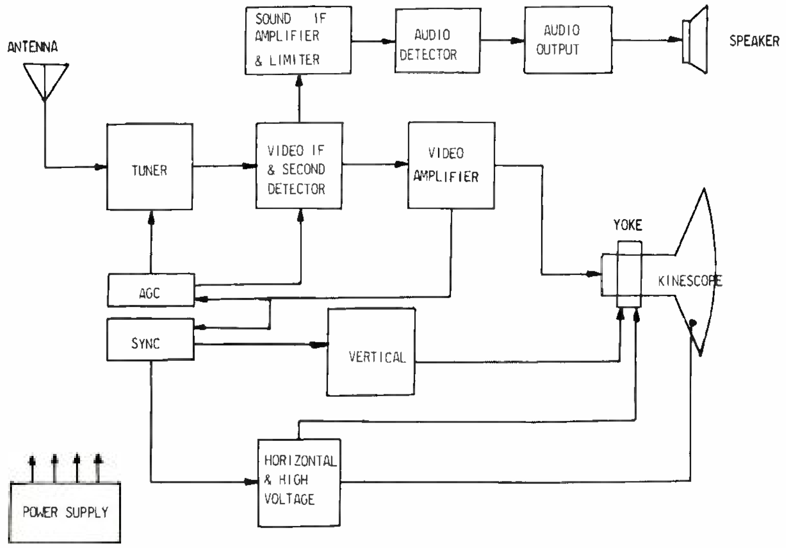

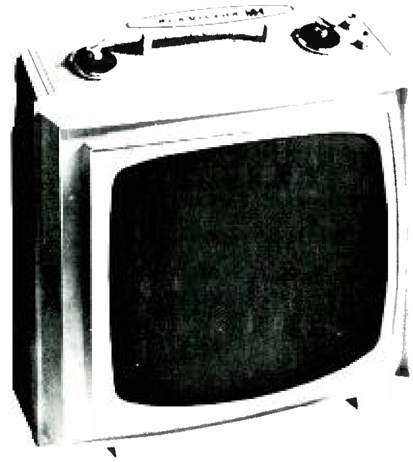

Fig. 1—KCS152 16-inch portable TV receiver (diagram and photo).

ECONOMICAL, LOW B+, MONOCHROME TV RECEIVER WITH HIGH PERFORMANCE

For several years, there has been a continuing program in the RCA Victor Home Instruments Division to design an economical, low B+ monochrome television receiver of high performance. The low B+ design offers low power, low operating temperature, and high reliability; while many have been marketed by the industry, their design approach did not achieve a performance adequate to meet RCA standards. Now, an economical low B+ receiver meeting RCA requirements of high performance has been engineered as described herein, and is now in production. Low cost is attained by more-efficient circuits, new components, and new tubes. Solutions were found for the problems, normally associated with low B+ supplies, of adequate video drive, deflection, and high voltage. Performance data taken on actual production samples shows it to be of commercially acceptable performance.

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RCA Victor Home Instruments Div., Indianapolis, Ind.

Over the years, television receivers have undergone marked changes in size and performance. Significant cost reductions have been made possible by new materials, components, and circuit designs. However, in the highly competitive home TV receiver business, there is always a market for a receiver offering adequately high performance but at reduced cost. In past years, our competitors have tried using low $B+$ supplies to achieve this end; however, such receivers were not of the quality required by RCA performance standards. But now, using new tubes and new circuit ideas, a 16-inch portable monochrome TV receiver has been designed as a combined effort of several RCA Home Instruments engineering groups, supported by RCA Electronic Components and Devices on design of the new tubes required. The receiver described herein has been in quantity production for several months and has been favorably received. The low cost and high performance was achieved by using a low $B+$, or 145-volt, power supply in addition to the proper utilization of new components and new efficient circuits; improved reliability was realized through the lower ambient temperatures with the low $B+$ supply.

Final manuscript received January 25, 1965

Major circuit revisions were made in the video, vertical, and horizontal circuits, and circuit innovations were made in the tuner, video IF, sound IF, sync and AGC to maintain or improve performance.

CIRCUIT DESIGN

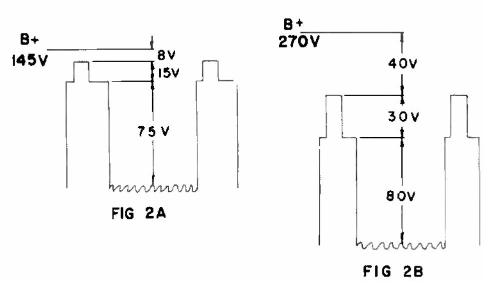
The basic 16-inch portable TV receiver is diagrammed in Fig. 1.

Tuner

To reduce cost, the tuner utilized three tuned circuits instead of four. A frame grid pentode, the 3GK5, was used as the RF amplifier to obtain a high sensitivity and low-noise figure. The lower $B+$ voltage required that the mixer and oscillator be operated separately from the 145-volt source; the usual practice for a 270-volt $B+$ receiver is to have the mixer and oscillator in series for DC.

The RF input was made to accept either a 300-ohm or 75-ohm input. This feature reduced the cost of the built-in monopole antenna system, as it eliminated a balun previously used to match the monopole to a 300-ohm input. The monopole antenna connects directly to

Fig. 2—Composite video signal at video plate: a) 145-volt B+; b) 270-volt B+.



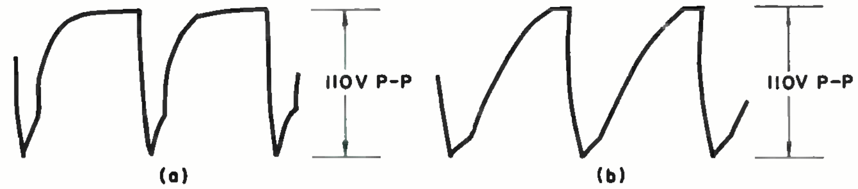


Fig. 3—Output waveshape of potter oscillator.

the 75-ohm input of the RF stage; when an external antenna is used, a 300-to-75-ohm balun is switched into the input circuit to match the 300-ohm transmission line to the 75-ohm RF-stage input.

Video IF and Second Detector

The required overall IF gain was obtained in a two-stage amplifier by using a low-loss link circuit and high G_m frame-grid tubes; the link circuit connects the mixer output to the first IF input. This circuitry includes IF traps for proper selectivity, in addition to a link cable connecting the tuner output to the IF input. By using efficient trap circuits, the link circuit gain was increased sufficiently to allow the use of a lower-gain, lower-cost mixer.

The second IF amplifier is biased for maximum signal-handling capability. The AGC is applied to the first amplifier, as in a normal two-stage IF. The second detector is basically conventional except for the transformer which is added for coupling the 4.5-Mc/s sound signal to the sound IF amplifier and limiter.

Video Amplifier, Sync, and AGC

A unique feature is the method of obtaining sufficient contrast using a low $B+$ supply. The required video drive to the picture tube of 90-volt peak-to-peak video information is obtained by avoiding amplification of the sound signal in the video amplifier. The AGC is designed so that the sync portion of the signal is compressed. Fig. 2 shows the comparison between the 145-volt $B+$ chassis and its predecessor of the composite video signal with a modulation depth of 85%. Since the sound takeoff is ahead of the video amplifier, sound buzz due to sync is no problem during reception or during initial warmup when AGC has not begun to operate.

Improved noise immunity for the sync and AGC is inherent in this system. Since sync tips are operated near $B+$ level, any noise pulses that exceed the sync tips are clipped or suppressed in the video amplifier; thus, noise never materially upsets sync or AGC performance. The AGC system is a conventionally keyed system using a triode.

TABLE I—Comparison of 140-Volt B+ Receiver and 270-Volt B+ Receiver

Characteristic	140-Volt Receiver	270-Volt Receiver
Sensitivity μV (input for 1-V DC output at the second detector)		
Low channels average	10	7.5
High channels average	11	10.0
Audio output, W (at 10% distortion)	0.8	1.0
Luminance information in video V	75	80
Composite video output, V	90	110
Kine anode voltage, kV	18	18
B+ supply, V	145	270
Flyback transformer ambient, °C	46	56
AGC	gated triode	gated pentode
Noise immunity	good	good
Power consumption, W	115	143
Vertical deflection power, W	7.2	10.2
Horizontal deflection power, W	30	38

Sound IF, Audio Detector, and Amplifier

To utilize the video amplifier effectively, the 4.5-Mc/s sound IF was taken off at the second detector without using the video amplifier for 4.5-Mc/s amplification. The takeoff transformer couples the sound IF to the pentode IF amplifier and limiter which in turn provides an input for the audio detector. The audio detector is a locked-oscillator quadrature detector using the boosted $B+$ supply to maintain its optimum performance.

The audio output is a Class A pentode circuit with the plate connected directly to the $B+$ supply; thus, the $B+$ dropping resistor and its associated capacitor are eliminated. The audio output of 0.8 watts with 10% distortion is essentially equivalent to some higher cost, higher $B+$ receivers.

Horizontal

Requirements for the horizontal deflection were difficult to satisfy. To achieve the required performance the following circuits were used:

1) *Screen width control*—the screen-width control was used for economy and efficiency. The normal width coil has an appreciable circuit loss and is more expensive.
2) *Horizontal oscillator*—a potter oscillator (cathode-coupled multivibrator) was chosen because the output can be readily shaped for optimum performance at low $B+$. The often used synchroguide oscillator produces a sawtooth drive for the horizontal output tube, whereas, the output of the Potter Oscillator has the desired shape (see Fig. 3).
3) *New horizontal output*—a tube was designed by Electronic Components and Devices (22JU6) to deliver high-peak currents at very low plate voltages.
4) *Damper*—a high perveance damper tube (17BS3) with high current capabilities provides greater efficiency, thus more scan and high voltage.

The efficiencies gained at the lower $B+$ also resulted in better linearity.

Vertical Deflection

Adequate vertical deflection with low $B+$ and high kinescope anode voltage is difficult to achieve; this problem was solved by using an efficient vertical output transformer, a toroidal vertical yoke winding and a new vertical output tube. An autotransformer was used to match the vertical output tube to the yoke for maximum circuit efficiency. The fewer laminations required in an autotransformer resulted in a cost savings. A new yoke with a toroidal vertical winding designed by Home Instruments Component Design group provides added sensitivity.

The vertical output tube in a low $B+$ receiver must meet certain requirements; these include a low-knee, high-peak plate current, and a high-peak plate pulse rating. An RCA-developed 15KY8 was used to meet these.

The comparison of efficiency between two 18-kV deflection systems of 145 volts and 270 volts can be seen in Table I. The total power consumption of the 145-volt system is only 70% of that required by the 270-volt system.

Power Supply

The 145-volt and 270-volt power supplies are shown in Fig. 4. The 145-volt supply uses a half-wave rectifier with a choke and two electrolytics for filtering.

A single line-operated half-wave rectifier utilizing conventional surge protection did not provide sufficient $B+$ voltage for this receiver; this problem was solved by using a series combination of a thermistor and fusistor. When the receiver is turned on the thermistor has a resistance of 16 ohms to protect the diode from "turn-on" surge currents; after warmup, the resistance of the thermistor drops to 1 ohm. The circuit using the thermistor substantially

Fig. 4—Power supply: a) 145-volt B+; b) 270-volt B+.

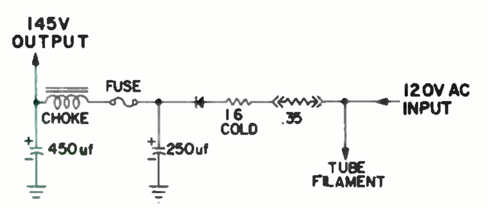


FIG. 4A

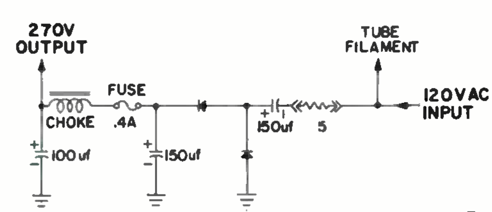


FIG. 4B

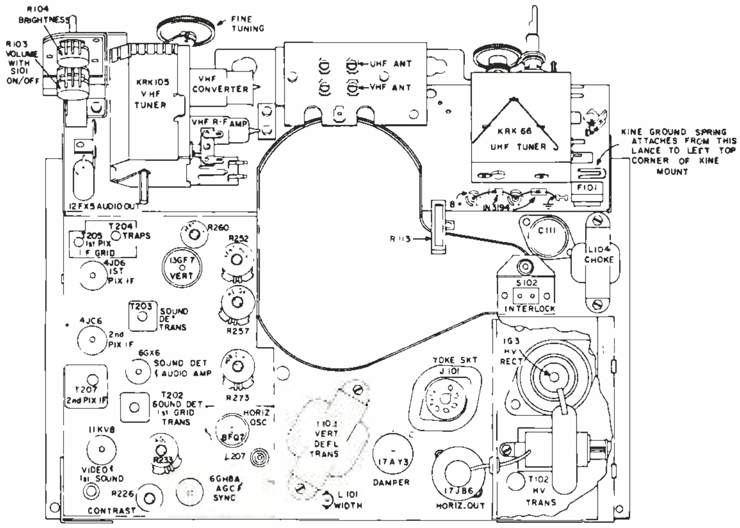


Fig. 5—Rear view of KCS146, 270-volt receiver layout.

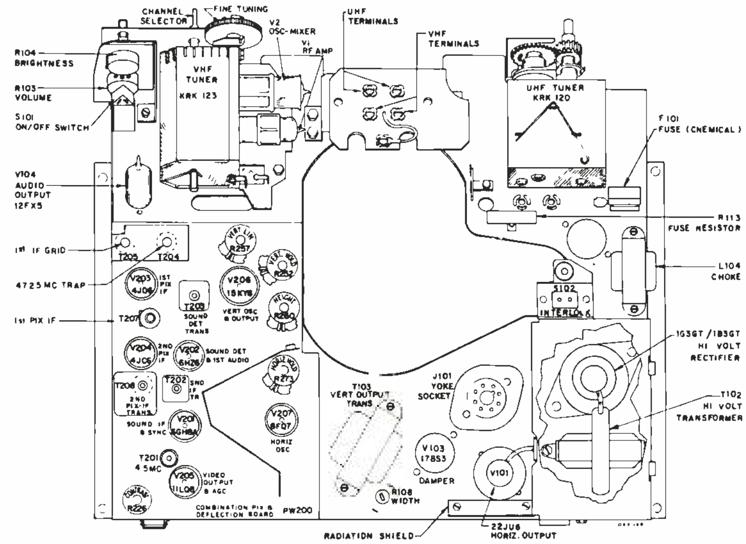


Fig. 6—Rear view of KCS152, 145-volt receiver layout.

reduces the surge current for improved reliability in addition to providing a higher $B+$ voltage for the receiver.

Some advantages for the low $B+$ supply are:

1) Lower capacitor voltage ratings throughout the receiver reduce costs.
2) Less heat dissipation in components increases reliability. High-wattage dropping resistors are not needed. Power tubes operate at increased efficiency; thus required performance is obtained with less power dissipation.
3) Cost savings are realized by eliminating dropping resistors and decoupling capacitors no longer needed in some circuits.

CHASSIS LAYOUTS

To save tooling costs, it was essential to retain the same cabinet and chassis of a prior model, 64A02, the KCS146. Pictures of the two chassis layouts are shown in Figs. 6 and 7; the chassis is basically the same for both instruments. The printed circuit board is of the same mechanical design and mounting; board-mounted controls are mounted in the same manner; the tuner mounting and antenna board are identical.

OVERALL PERFORMANCE COMPARISON

A brief summary of the overall performance of the two instruments is given in Table I. The performance data represents a production average for both instruments, as manufactured at the Bloomington plant. The instruments have been produced in sufficient quantities to assure accurate statistics.

The higher video gain of the cost-reduced receiver indicates that the overall gain from the antenna terminals to the kinescope cathode should be very similar. The actual luminance portion of the video signal is much closer to the original set than would be anticipated. A slight reduction in kinescope screen voltage in the low $B+$ receiver brings the contrast levels even closer together. Table I also illustrates the lower wattage of the receiver, and the lower operating temperature indicated earlier. It is interesting that the difference in nominal sensitivity between the two receivers is less than the variations encountered in production with either.

CONCLUSIONS

The feasibility of using a low $B+$ supply in a commercially satisfactory receiver has been proven. Longer life and improved reliability will result from the lower power dissipations and temperatures in the receiver. Efficient design has led to a lower-cost instrument. Performance level goals established have been demonstrated and proven through actual production.

ACKNOWLEDGEMENTS

The authors appreciate the assistance of engineers in Black and White TV Product Design who worked diligently on the receiver; also acknowledged are the contributions of the Electronic Components and Devices, and the Home Instruments TV Tuner Design and Component groups. Particular appreciation is expressed to R. J. Lewis, our manager, for backing the project wholeheartedly and seeing it through difficult decisions.

PAUL C. WILMARTH received the BSEE degree from the Pennsylvania State College in June, 1952. From 1952 to September, 1963, he was with the Design and Development section of Philco Radio and Television Engineering. His work included all phases of the design of a television receiver and more recently had the responsibility for the design of all portable receivers. He is presently with the Television Engineering Department of RCA Home Instruments Division, Indianapolis, Indiana, where he is also engaged in the design of portable television receivers. He is a member of Eta Kappa Nu.

LOREN R. WOLTER received the BSEE from Iowa State University of Science and Technology, Ames, Iowa in May, 1959. He is enrolled in the Master's Degree Program at Purdue University, Indianapolis campus. In 1959, Mr. Wolter joined RCA in the design of IF amplifiers, sound IF and audio sections of the black and white TV receivers. He is now a project co-ordinator in the design of black and white TV receivers. He is a member of the IEEE, and an RCA Engineer Editorial Representative.

L. P. THOMAS received the BSEE from Clemson University, Clemson, South Carolina in 1947, and has taken courses in business administration at the Wharton School of the University of Pennsylvania. In 1947, Mr. Thomas joined the television engineering section and became responsible for the design and development of the video, sync separator, AGC, and noise cancellation circuitry of RCA's black and white television receivers. He also has designed remote control circuits, automatic contrast and brightness control circuits, and other items related to the television field. Mr. Thomas has 18 issued patents plus patents pending and has written other articles and lectures. He is a senior member of the IEEE and is a leader in the television engineering section at present.

L. R. Wolter

P. C. Wilmarth

L. P. Thomas

RF POWER TRANSISTORS

Important New Advances in Performance and Economics

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Surveyed here are important advances in RF power transistors that significantly improve their performance while reducing their cost. These advances extend high-frequency power transistors into new applications in mobile, aircraft, and military equipment—with FM, AM, and SSB operation practical. The overlay type of transistor is completely changing high-frequency communications equipment design. Rapid progress is expected to continue.

The first RF power transistor, introduced in 1958, had the rather modest performance of 100 mW of output power at a frequency of 100 Mc/s. In spite of the fact that major improvements in power-frequency performance were achieved in each succeeding year, by 1963 only a few transmitters had been converted to solid-state—including low-power telemetry, citizens-band equipment, and portable 175-Mc/s-band sets. Although the use of transistors provided the advantages of increased reliability, lower power drain, elimination of DC-to-DC converters in battery-operated portables, and smaller size in these applications, the vast majority of military and commercial communications transmitters appeared to be considerably out of the range of transistorization. Some hybrid schemes in which semiconductor devices were used up to the final stage were explored in military designs because of reliability, but a meaningful swing to solid-state appeared remote. The major barriers were *economics* (tubes were still at least an order of magnitude less expensive than transistors) and *performance* (transistors were limited to low-power, narrow-band, class C applications).

Final manuscript received April 28, 1965.

* Since this article was written, the authors have transferred to new responsibilities. Dr. Donahue is now Manager, Industrial Semiconductor Operations—and B. A. Jacoby is now Mgr., Marketing, Integrated Circuits Dept.

THE "OVERLAY" TRANSISTOR

In 1964 the state-of-the-art of RF power transistors abruptly moved to a new level with the introduction of the first *overlay* transistor,[1] the RCA 2N3375. In an overlay transistor structure, a substantial number of individual emitter sites are connected in parallel and used in conjunction with a single base and collector region. In the 2N3375, for example, 156 emitters are formed and interconnected in a single silicon chip by means of diffusion and metalization.

One of the important features of the overlay structure is that it provides for a significant increase in emitter edge or periphery, which is proportional to current or power, and a simultaneous decrease in emitter and collector areas, which are proportional to input and output capacitances. The ratio of current to input and output capacitance defines the input and output time constants of the transistor. The overlay structure thus affords a several-fold increase in these ratios or time constants over *all previous* comb, star, snowflake, sharkstooth, and similar structures. The final result is a marked improvement in power output, gain, efficiency, and frequency capability. (A description of overlay design and fabrication is given in another paper.[1])

MULTIPLICITY OF OVERLAY TYPES

Many degrees of freedom are permitted by the overlay approach to RF power-transistor design. As a result, a number of designs intended for a variety of end uses have been announced, and many more are in development. Table I lists a few of the general-purpose types which demonstrate the range of performance available. The 2N3866 is of

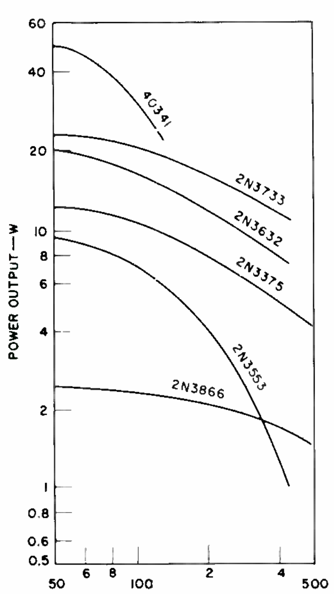


Fig. 1—Typical power output vs. frequency for RCA high-frequency power transistors.

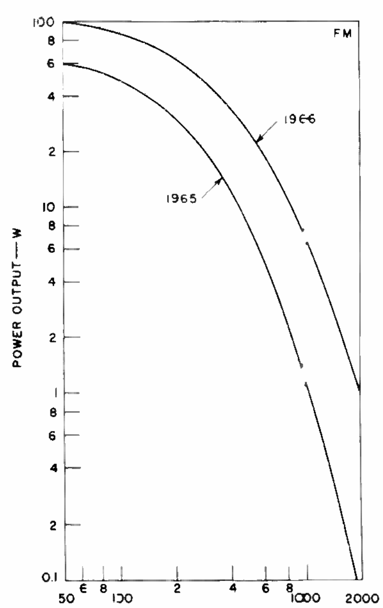
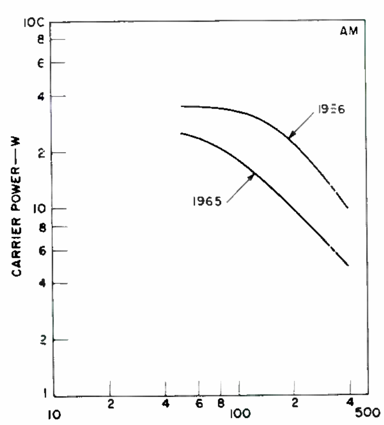


Fig. 2—Comparison of present and predicted equipment capability for FM applications.

Fig. 3—Comparison of present and predicted equipment capability for AM applications.



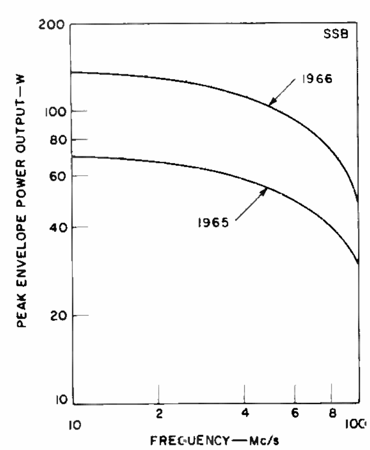


Fig. 4—Comparison of present and predicted equipment capability for SSB applications.

DR. D. JOSEPH DONAHUE received the BS in Physical Chemistry in 1947, the MS in 1948, and the PhD in 1951, all from the University of Michigan. Upon graduation he joined the RCA Electron Tube Division in Lancaster, where he was engaged in development work on pickup tubes and tricolor picture tubes, particularly on the mask and screen of the tricolor tube. In 1958 he transferred to the Semiconductor Division in Somerville as a Manager in the Advanced Development section. In 1960 he was appointed Manager of Advanced Development for the Semiconductor and Materials Division. In the Advanced Development area he was associated with a wide variety of advanced material, technology, and devices programs, including gallium arsenide, tunnel diodes, high-frequency transistors, and field-effect transistors. In 1962, he was appointed Manager of Engineering for the Industrial Semiconductor Operation. In this capacity he is responsible for the design, development, application, and pilot production of a very broad line of power transistors, rectifiers, and SCR's.

B. A. JACOBY joined the RCA Components Division in 1952. Prior to that time, he worked for an electrical contractor and distributor, and also was employed by the State of New York as an actuary. In the Components Division, he held various positions in warehousing, purchasing, field sales, and product sales administration. He assumed his present position as Manager of Market Planning for Industrial Semiconductors in July of 1963.

particular interest because it has very high gain, 10 to 12 db at 400 Mc/s and 20 db at 100 Mc/s. Overlay transistors other than those listed in the table have been developed for specific applications such as citizens-band radio, 50-Mc/s and 175-Mc/s mobile transmitters (13.5 and 28 volts), 135-Mc/s AM aircraft transmitters (13.5 and 20 volts), and driver and predriver stages for each of these applications. Transistors specifically designed for single-sideband (SSB) operation will soon be added to this list. Fig. 1 shows typical curves of power output as a function of frequency for the transistors listed in Table I.

An extremely important feature of high-frequency transistors is their packaging. Low lead inductance, good thermal conductivity, and isolation of the collector are all-important considerations. Most overlay transistors use a specially designed 7/16-inch double-ended isolated-stud case, the TO-60. Lower-power devices employ a TO-39 case that has a solid-steel header for good thermal conductivity. New cases will be designed in the future to provide higher resonant frequencies and lower parasitic inductances so that future overlay devices can be fully exploited.

ECONOMICS

The most remarkable aspect of the RF power-transistor field is that improvements in performance have gone hand-in-hand with cost reduction—*and will probably continue to do so.* The overlay transistors represent improved performance at prices that are opening the commercial communications market. Their low cost is largely attributed to the comparatively small size of the overlay silicon transistor chips (0.030 by 0.030 inch for the 2N3375). This small size results in higher yields because of the lower probability of imperfections, and also permits more gross transistor chips per wafer. As increasing penetration of the commercial communications market adds volume to this favorable situation and as the new techniques are sharpened with experience, RF power-transistor prices will experience considerable reductions.

The use of overlay transistors also provides further opportunities for cost reduction in equipment design as a result of increased gain per stage, higher power per transistor, and elimination of voltage converters in battery-operated sets.

MARKETS

The recent availability of RF power transistors that are capable of handling a wide range of powers through an extended frequency range and that offer much improved reliability and maintainability is reshaping the outlook for all-solid-state transmitters. A very wide variety of RF power equipment is now being designed entirely with transistors; the types of equipment include the following:

mobile	commercial aircraft
radiosonde	military aircraft
telemetry	rescue beacon
troposcatter	aerospace (ultra-high reliability)
radio relay	military tactical
radar transponder	communications
citizens band	community antenna TV
portable	
sonobuoy	

Of particular interest is that transistors have invaded such applications as mobile, military, and aircraft communications, which require power levels of tens of watts and the capability of transistor use in FM, AM, and SSB circuits. The power outputs that can presently be obtained from practical equipment designs at different frequencies for FM, AM, and SSB systems are shown in Figs. 2, 3, and 4, respectively. Also included are estimates of equipment capabilities one year from now. These curves reveal that transistors have come a long way in the past year and are moving ahead rapidly.

FM CIRCUITS

Frequency modulation is used extensively in such communication applications as telemetry, microwave relay, and portable and mobile equipment. Fig. 5 shows a typical three-stage power-amplifier circuit suitable for telemetry application. The input stage uses a 2N3553 overlay transistor operated as a common-base 100-to-200-Mc/s frequency-doubler circuit. The second stage of the amplifier uses a 2N3375 overlay transistor as a 200-to-400-Mc/s common-emitter frequency-doubler circuit. The final stage consists of two 2N3375's operated in a parallel arrangement. This amplifier is capable of providing a power output of 10 watts at 400 Mc/s. An overall power gain of 16 db is obtained, as well as a quadrupler frequency-multiplier function.

Fig. 6 shows a 35-watt 175-Mc/s FM mobile transistor amplifier. This transmitter uses a family of overlay transistors which have been specially designed for direct use from 13.5-volt automobile batteries; thus there is no need for a DC-to-DC voltage converter. The output section of the transmitter contains three 40282 transistors in parallel. A separate matching network in the base of each output transistor permits drive adjustments to equalize collector currents. The overall DC-to-RF efficiency of this entire transmitter is approximately 60%. The first three stages of the amplifier could be used in portable application as a 12-watt amplifier working into a 50-ohm load.

AM CIRCUITS

One of the most common uses of amplitude modulation is in the 27-Mc/s citizens band. For example, a typical 5-watt (DC input) citizens band transmitter can handle 3 watts of carrier power, and can deliver up to 10 watts of peak power under 100% modulation.

Amplitude modulation is also used extensively in aircraft communications. Fig. 7 shows a 10-watt, 135-Mc/s AM transmitter of the type used in small aircraft. Operation directly from a 13.5-volt supply eliminates the need for a DC-to-DC converter. Amplitude modulation greater than 95% is achieved in this

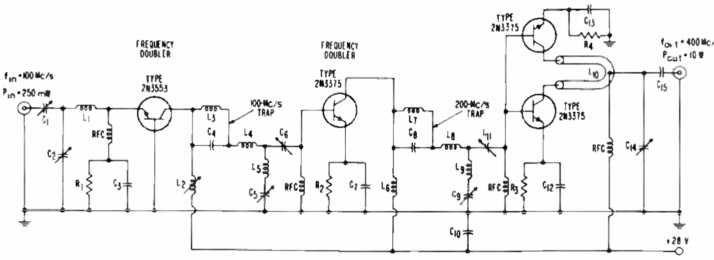


Fig. 5—Three-stage FM power amplifier for telemetry applications.

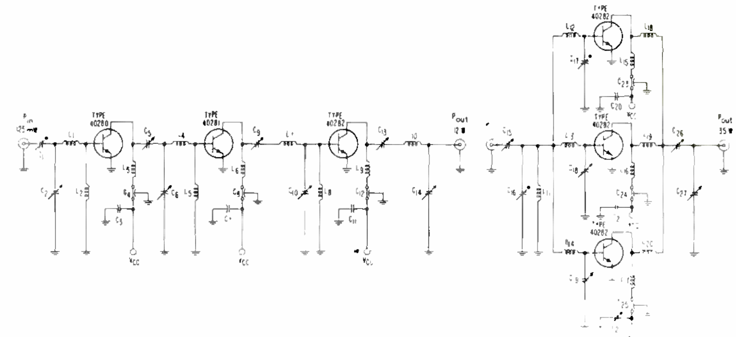


Fig. 6—FM mobile transistor amplifier; 35-W, 175-Mc/s.

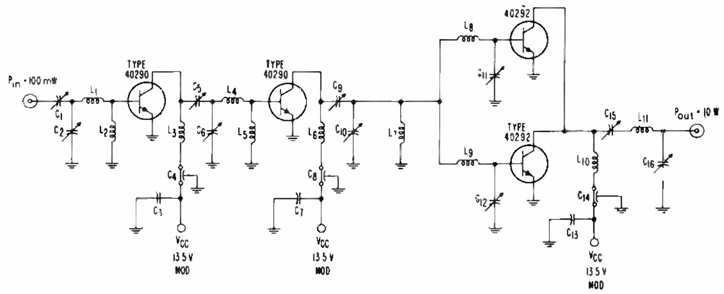


Fig. 7—AM amplifier; 10-W, 135-Mc/s.

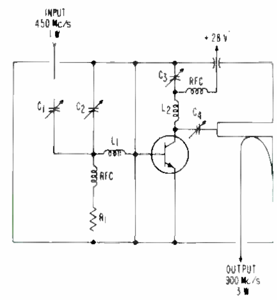


Fig. 8—Transistor doubler circuit; 450-to-900-Mc/s.

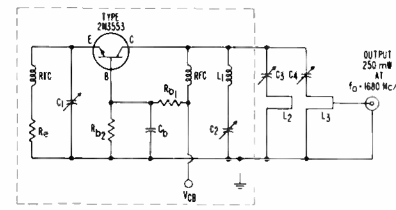


Fig. 9—Transistor oscillator–frequency-multiplier circuit.

amplifier by modulation of the supply voltage to all three stages. The separate input matching network for each output transistor permits drive adjustments to equalize collector currents. A technique developed by RCA for measuring voltage breakdown under RF conditions allows the 40292 transistors to be checked under conditions which closely simulate actual operation.

FREQUENCY MULTIPLICATION

Transistor frequency multiplication, which has been used for many years at small signal levels, has been extended to power levels as a result of improved transistor design. In this type of operation, the collector-to-base diode of a transistor is used as a varactor to obtain frequency multiplication at the output signal. Frequency doubling with power gain (Fig. 5) is becoming commonplace and has begun to eliminate the use of varactor diodes below 400 Mc/s.

Of even greater significance are the transistor frequency-multiplication studies now underway which extend the operating range of transistors far beyond the cutoff frequency of the basic transistor structure. The 2N3375, 2N3553, and 2N3866 have been found to be particularly suitable for this mode of operation as doublers, triplers, and quadruplers. Substantial power output has been obtained at frequencies approaching 2,000 Mc/s.

Fig. 8 shows a 450-to-900-Mc/s transistor doubler circuit. Lumped elements are used for the input and idler circuits; a coaxial cavity is used for the output circuit. The 2N3375 transistor is connected in a common-emitter configuration and is located inside the cavity in a position for optimum electrical field for a second-harmonic output. Power is taken out through an inductive coupling loop near the shorted end of the cavity. An input of one watt at 450 Mc/s produces an output of 3 watts at 900 Mc/s. A 2N3866 in the same circuit provides an output of one watt at 900 Mc/s from an input of 0.25 watt at 450 Mc/s.

Higher-frequency operation can be obtained with the combination oscillator and frequency multiplier shown in Fig. 9. In this circuit, the 2N3553 oscillates at a frequency of 420 Mc/s and quadruples to an output frequency of 1,680 Mc/s. An output power of 250 mW is obtained.

TABLE I — Minimum Performance of High-Frequency Overlay Transistors

Type	Case	Power Output, watts	Frequency, Mc/s
2N3866	TO-39	1.0	400
2N3553	TO-39	2.5	175
2N3375	TO-60	3.0	400
2N3632	TO-60	13.5	175
2N3733	TO-60	10.0	400
40341	TO-60	30.0	50

Transistor frequency multiplication is extending the frequency range of power transistors well into the microwave region. Many advantages will result from this approach, including simpler system design, higher reliability, and reduced cost, size, and weight. The next year will bring significant advances in the power and frequency that can be obtained from this mode of operation.

SUMMARY

The year 1965 will mark the entry of high-frequency power transistors into a wide variety of new applications, such as mobile, aircraft, and military equipment; FM, AM, and SSB operation have all been made practical. The severe linearity requirements of SSB have been met by the development of a specifically designed overlay transistor. Transistor frequency multiplication has extended the range of power transistors to 2,000 Mc/s.

The improved performance and lower cost of high-frequency transistors made possible by overlay designs have completely changed the high-frequency communications field. Future progress is expected to continue for the next few years at a very rapid rate.

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THE "OVERLAY"

A New UHF Power Transistor

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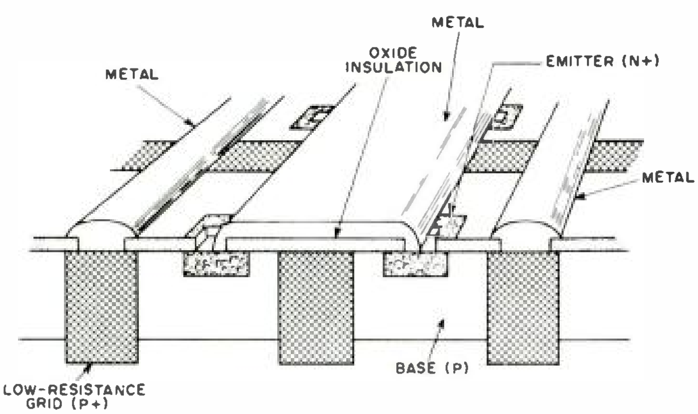


Fig. 1—Cross section of completed structure of overlay transistor.

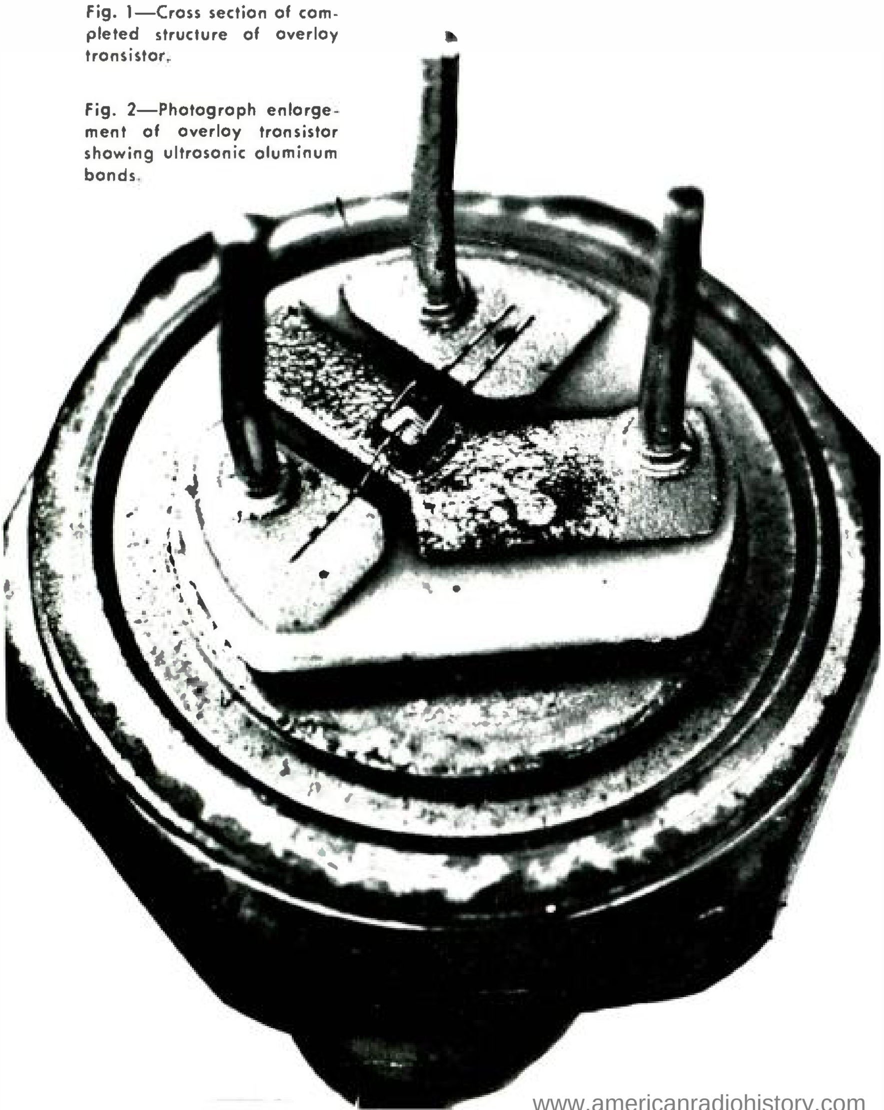
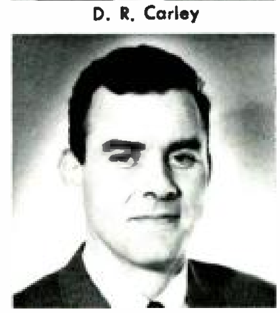


Fig. 2—Photograph enlargement of overlay transistor showing ultrasonic aluminum bonds.

In recent years there has been considerable emphasis on the development of transistors capable of operation at high frequencies and high power levels—stimulated by the need for increased reliability and efficiency in all-solid-state telemetry systems. Transistors have been required for final output stages, as power sources for varactor multiplication, and as amplifier-multipliers. Power transistors are also useful in output stages of citizens-band or mobile equipment, and as high-current switches. The RCA-2N3375 silicon overlay transistor is capable of high-power UHF operation far beyond that achieved by previous state-of-the-art devices. Prior to development of the 2N3375, the best commercially available transistors were capable of producing power outputs of only 30 milliwatts at a frequency of 500 Mc/s. The overlay transistor can provide power of 10 watts at 400 Mc/s.

D. R. Carley



P. L. McGeough

J. F. O'Brien

THE development of power-transistor structures has included two major areas: internal design and surface geometry. Earliest junction transistors were made of germanium and employed alloying and regrowth to form the junctions; n-type germanium was used as the starting material, and indium was used as the p-type dopant in the formation of the emitter and collector. The first step in the evolution of these transistors was the development of diffused-base structures, which could be fabricated of either germanium or silicon. The emitter in these structures was formed by either alloying or diffusion. Today, diffused-base types constitute the majority of silicon transistors available.

Transistors incorporating diffused emitters and bases were further improved by the development of both epitaxial and "triple diffused" techniques which substantially reduced the collector series resistance. The collector base junction in silicon transistors has recently been changed from the mesa-type construction (formed by masking and etching away of the base region outside the active area) to the planar type. In the planar transistor, the collector-base junction is defined early in the fabrication.

Silicon has replaced germanium in high-frequency power transistors for several reasons, the most important being higher-operating-temperature capability and an elaborate technology built around the properties of silicon oxide. The higher maximum temperature limit permits more dissipation capability for a given collector area, and thus minimizes collector capacitance. The second advantage of silicon is that its oxide acts as a diffusion mask. Thin films, only 2,000 to 3,000 angstroms in thickness, completely mask the commonly used n-type and p-type diffusants phosphorus and boron. The silicon oxide, in turn, is capable of being formed by etching; therefore, very precise geometries can be used to define the emitter and base regions.

In early transistor designs, a disadvantage of silicon was the slower diffusion time of carriers through the base region, which caused a lower frequency response for a given base width in silicon than in germanium. As base widths became smaller and smaller, however, other delay times dominated and the slightly longer base transit time in silicon became a less important consideration.

The geometry of the emitter has been particularly important in obtaining high-current-handling capability. The current flowing through the base region between the emitter and the collector causes a lateral voltage drop that produces maximum forward bias at the edge of the emitter closest to the base contact. This bias concentrates almost all the emitter current at the emitter-base periphery; therefore, the center portion of the emitter area injects almost no current.

This edge-injection phenomenon has led to design changes of the emitter from the circle type to the line type, to the comb type, and finally to the overlay structure. Each of these design changes, largely pioneered by RCA, produced more edge with less emitter area.

The maximum frequency of oscillation f_{max} of a junction-transistor structure is:

$$f_{max} = (PG)^{1/2} F = \frac{1}{4\pi} \left[\frac{1}{r_{bb'}\, C_c\, \tau_{ec}} \right]^{1/2} \quad (1)$$

where PG is the power gain, F is the frequency of operation, $r_{bb'}$ is the base-spreading resistance, C_C is the collector capacitance, and τ_{ec} is the emitter-to-collector transit or signal-delay time.

This equation was derived from a low-level class A analysis, but can also serve as a guide to performance in the more usual class C circuits. To a first approximation, the frequency f_{max} at which the power gain is unity is independent of collector area. Although the collector capacitance C_C is directly dependent on the collector area, the value of $r_{bb'}$ varies inversely with area. For example, if the stripes and base of an interdigitated or comb-type structure are made twice as long, the capacitance C_C is doubled but the $r_{bb'}$ is cut in half. Thus, the length of a transistor can be extended and the power dissipation and current-handling capability improved without any increase of the $r_{bb'}C_C$ product.

The collector-to-emitter transit time τ_{ec} is comprised of four terms: 1) the charging time of the emitter capacitance and the emitter resistance, 2) the transit time through the base, 3) the transit time through the collector depletion region, and 4) the charging time of the collector capacitance and the collector series resistance. The last term is usually negligible in triple-diffused or epitaxial construction. Of

Final manuscript received April 15, 1965

DONALD R. CARLEY received the BS in Physics from the University of Michigan in 1957. After graduation he joined the RCA Semiconductor Division in Somerville as a junior engineer in Advanced Development, where he worked on an all-diffused germanium transistor for horizontal-deflection usage. This project culminated in the development of the first all-diffused high-power, high-voltage germanium power transistor. In 1960 he was promoted to his present position of Engineering Leader in Industrial Transistor Design. He has concentrated on the development of high-power, high-frequency transistors. His responsibilities have included the development of a 5-watt 200-megacycle transistor, a 300-watt 300-volt power transistor, and a fast-switching 20-ampere power transistor. Most recently he has been responsible for the development of a family of transistors utilizing the "overlay" design, for which a patent has been filed in his name. The first overlay transistor, the 2N3375, has led to many different devices, including transistors capable of 60 watts output at 50 megacycles, a transistor for application in single-sideband equipment, a 20-watt 430-megacycle transistor, and a 1-watt 1000-megacycle transistor. Mr. Carley received the RCA Electronic Components and Devices "1964 Engineers Achievement Award" for his contributions to high-frequency power transistors, and the "David Sarnoff Outstanding Achievement Award" for 1965 for the design and development of the overlay transistor.

PATRICK L. McGEOUGH received the BSEE from Newark College of Engineering in 1961. From 1956 to 1959 he worked at Bell Telephone Laboratories as a Senior Technical Aide in the area of research and development of thin metal films deposited by various vacuum techniques for use as passive circuit components. He joined the Industrial Transistor Design Group at the RCA Semiconductor and Materials Division as an engineer in 1961. Since that time he has worked on the design and development of high-frequency transistors. His design work has involved the processes associated with fabricating these devices, concentrating specifically in the area of high-vacuum techniques for applying metallizing layers. He worked on the device design and processing techniques associated with the development program of the 2N3375 "overlay" transistor. Most recently he has been engaged in the design and process development of a developmental 1-watt, 1-gigacycle overlay transistor.

JOSEPH F. O'BRIEN received the BS in Physics from Fordham University in 1951. He has done graduate work in Physics and Electronics at Northeastern University and at Newark College of Engineering. Prior to joining RCA, he was employed by Evans Signal Laboratory from 1951 to 1955 as a Physicist, by Raytheon Manufacturing Company from 1955 to 1956 as a Development Engineer, by International Telephone and Telegraph Laboratories from 1956 to 1960 as a Research Physicist, and by Bendix Corporation, Semiconductor Division, as a Senior Project Engineer. During this time his experience consisted of the design, development, and fabrication of semiconductor devices including rectifiers, varactor diodes, tunnel diodes, controlled rectifiers, and associated material evaluation programs. He joined the RCA Semiconductor and Materials Division in 1961 as a design engineer in the Industrial Transistor Design Group. Since then, his experience has been in the area of device design and fabrication of high-power, high-frequency silicon transistors. He was responsible for the development of photolithographic technology required in the fabrication of the 2N3375, and assisted in the transfer of the 2N3375 to a Model Shop operation. He is presently engaged in the design and investigation of new device structures to improve high-frequency performance. Mr. O'Brien is a member of the IEEE and the American Physical Society.

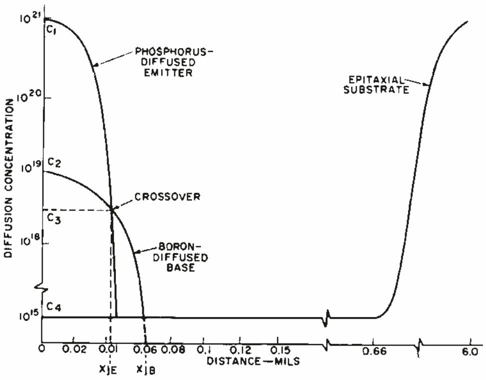


Fig. 3—Diffusion profile for 2N3375 overlay transistor.

the remainder, only the emitter transit time is current-dependent, as shown by:

$$\tau_e = r_e C_{ea} = \frac{KT}{qI_e} C_{ea} \qquad (2)$$

However, if the emitter edge is increased proportionally as the area of the emitter is increased, the fraction C_{ea}/I_e remains a constant. Provided suitable scaling is used, transistors can be enlarged to increase power-handling capability without deterioration of frequency response.

FEATURES OF OVERLAY TRANSISTORS

A new emitter electrode structure called *overlay* (Figs. 1 and 2) is used in power transistors such as the 2N3375. In this structure, a substantial number of separate emitters (156 in the 2N3375) are tied together by diffused and metalized regions. This approach provides an order-of-magnitude improvement in the ratio of emitter edge to emitter area and a proportional reduction in the input time constant τ_e. This type of design has established a new level of performance for high-power high-frequency transistors. It is anticipated that this surface geometry will replace the comb-type designs previously employed.

The desired overlay structure is fabricated by means of diffusion and photolithographic processes which provide oxide-masking techniques for geometry control of the diffused regions. Previous work by Frosch and Derick has shown that silicon dioxide can be employed as an effective barrier for preventing diffusants from reaching the silicon surface. The photolithographic process opens desired areas in the oxidized silicon surface to permit the subsequent introduction of phosphorus or boron dopant for the formation of electrical junctions. The diffusion process employs vapor-diffusion techniques which produce the diffusant profile shown in Fig. 3. Diffused junction depth and spacings are angle-lapped, stained, and then measured by interferometric techniques.

The 2N3375 is a planar epitaxial n-p-n transistor. It has a collector area of about 400 square mils, an emitter area of 40 square mils, and an emitter edge of 300 mils. Control of the precise tolerances needed to define the patterns in oxide placed several primary requirements on the fabrication process. In this process, five separate masks are used to define the structure. Spacing within patterns from these successive masks is as small as 0.1 mil. One of the most important phases of the fabrication of overlay devices was the design of photomasks that have: 1) pattern registration over a large area, 2) edge definition of ±0.01 mil or less, and 3) high contrast (opaqueness of emulsion and clear emulsion-free areas).

In addition, techniques were developed for applying the photosensitive material on the silicon wafer in films that are thin enough to provide high resolution but thick enough to provide protection of oxide during etching. Thin coatings of emulsion provide good resolution but tend to develop defects. Optimum coating thickness and extreme care in etching were required. The design and construction of an improved alignment fixture was also necessary to provide precise control of movements in the *X* and *Y* direction, isolation of the vertical motion from *X* and *Y* movements, and sufficient pressure to provide intimate contact between the wafer and the glass mask.

FABRICATION TECHNIQUES

Fabrication of overlay devices begins with large silicon wafers with a thin epitaxial layer. Almost 1,000 transistors are processed simultaneously on each wafer. Prior to the etching of patterns into the oxide, the wafers are cleaned and then coated with a light-sensitive emulsion such as any one of the Kodak photoresists. A few drops of the resist are placed on the surface, and the wafer is mechanically whirled to produce an emulsion that is 3,000 to 4,000 angstroms thick. A photomask is then placed in contact with the wafer emulsion and exposed. The opaque areas in the photomask block the light, while the clear areas permit passage of light to expose and thus polymerize emulsion on the wafer. The wafer is then placed in a developing solution. This phase of processing develops the image and removes all unexposed emulsion. The remaining resist is further polymerized by heat treatment to permit protection of the oxide during etching; the unprotected areas are then etched to remove the silicon oxide and produce the desired pattern for the subsequent diffusions. The etched-out pattern for the base is shown in Fig. 4.

Next, a p-type dopant such as boron is deposited and diffused into the etched-out area. A relatively light concentration is used for this over-all base formation. The surface of the base area is reoxidized during the diffusion.

The wafer is then re-coated with resist, and the p+ mask shown in Fig. 5, which has 0.3-mil grid lines, is aligned inside the previously defined base area. The wafer is exposed, developed, baked, and etched to accept the diffusion of a

Fig. 4—Etched-out pattern for base of overlay transistor.

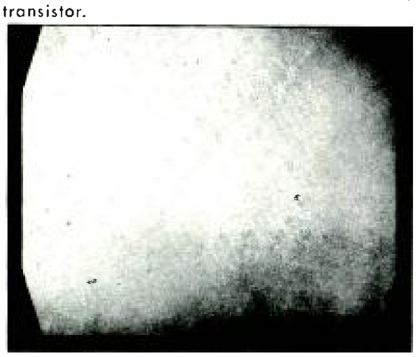


Fig. 5—Pattern of p+ conductive grid mask.

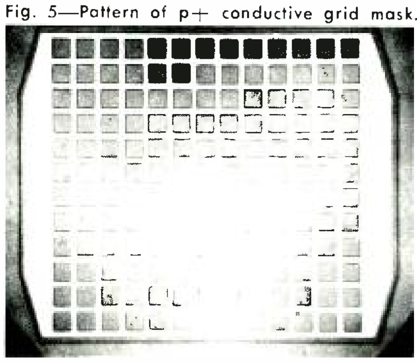
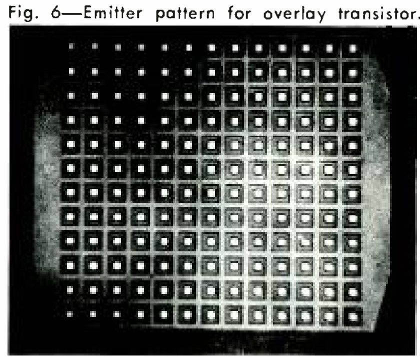


Fig. 6—Emitter pattern for overlay transistor.



p+ conductive grid into the wafer. This low-resistance grid distributes the base current and reduces the base-spreading resistance $r_{bb'}$, and thus improves the frequency response of the device. A reoxidation occurs during the p+ diffusion.

The emitter area is then defined in the oxide. Processing steps are repeated as in the case of the p+ pattern. The emitter pattern consists of 156 squares (0.5 mil) aligned so that the squares register in the center of the p+ diffused grid lines (Fig. 6). Registration and developing techniques must be good enough to keep edge variations in the pattern within 0.05 mil (12,500 angstroms) so that subsequent alignment is possible.

After reoxidation during emitter diffusion, contact areas for the emitter and base are defined in the oxide by means of the third and most difficult of the pattern registrations. The metal contact pattern (Fig. 7) requires a contact area of 0.3 mil in each 0.5-mil emitter and 0.3-mil-wide lines over alternate p+ regions.

Following the etching of the contact regions, aluminum is evaporated over the silicon wafer, and the wafer is then coated with photosensitive resist and processed as described above. Etching of the aluminum defines metal areas (Fig. 8) in which the emitters are connected to the center bonding area by aluminum stripes 1.5 mils wide. Each emitter metalization stripe makes connections to two adjacent rows of emitters. Contact to the base area is made at the metal base stripes.

Fig. 1 showed a cross section of a completed unit. The cross-hatched area indicates the p+ conductive grid. The emitter metalizing is insulated from the base by the silicon oxide and contacts the emitter in the open region.

Base current is distributed from the bonding area by the base metalization and by the p+ grid under the emitter metalizing. The emitter metalizing "overlays" the base.

After the wafer is scribed for pellet separation, the individual pellets are mounted in a 7/16-inch double-ended stud package that has an isolated collector termination. Aluminum wires are bonded to the pellet areas and the corresponding terminal posts (Fig. 2). The cap is sealed hermetically to the stud, and the leads are crimped to complete the package.

TABLE I—Electrical Characteristics, 2N3375

Characteristic	Test Conditions: DC Collector Volts		DC Base Volts	DC Current mA			Limits	
	V_{CB}	V_{CE}	V_{BE}	I_E	I_B	I_C	Min.	Max.
Collector-Cutoff Current, μA, I_{CEO}	—	30	—	—	0	—	—	0.1
Collector-to-Base Breakdown Voltage, BV_{CBO}, volts	—	—	—	0	—	0.1	65	—
Collector-to-Emitter Breakdown Voltage, BV_{CEO}, volts	—	—	—	—	0	0–200*	40**	—
Collector-to-Emitter, Breakdown Voltage, BV_{CEV}, volts	—	—	−1.5	—	—	0–200*	65**	—
Emitter-to-Base Breakdown Voltage, BV_{EBO}, volts	—	—	—	0.1	—	0	4	—
Collector-to-Emitter Saturation Voltage, $V_{CE(sat)}$, volts	—	—	—	—	100	500	—	1
Output Capacitance (Measured at 1 Mc/s), C_{ob}, pF	30	—	—	0	—	—	—	10
Thermal Resistance, θ_{J-C}, °C/W	—	—	—	—	—	—	—	15

Case temperature, 25°C Unless Otherwise Specified
* Pulsed through an inductor (25 mH); duty factor = 50%.
** Measured at a current where breakdown voltage is minimum.

PERFORMANCE

Parameters of the sealed units are measured both at DC and at UHF. Characteristics measured include junction breakdown voltage, leakage current, current transfer ratio, saturation voltage, thermal resistance, and junction capacitance. The DC specifications for the RCA 2N3375 overlay transistor are shown in Table I.

Measurements at UHF are made in the tuned-line, common-emitter, class C amplifier shown in Fig. 9. In this circuit, the adjustable stubs are tuned until an impedance match is obtained between the device input circuit and the signal source and between the power meter and the collector. The in-line wattmeter measures both the power delivered to the input of the device and the power reflected back to the driver stage. The condition of zero reflected power indicates an impedance match between the driver and the amplifier circuit. These tuned lines make it possible to obtain impedance matching over a wide range of frequency and impedance values for the same circuit components.

Tests were performance at various frequencies with a voltage of 28 volts applied between collector and emitter. The input circuit was biased by means of the parallel RC network shown in Fig. 9. Curves of typical performance for the 2N3375 are shown in Fig. 10. This device is rated for a minimum power output of 3 watts at 400 Mc/s and 7.5 watts at 100 Mc/s for 1 watt of drive. The minimum circuit efficiency of these units was 40% at 400 Mc/s and 65% at 100 Mc/s for 1 watt of RF drive.

Power output of 10 watts at 400 Mc/s can be obtained by parallel operation of the 2N3375. A later device, the RCA 2N3733, uses two 2N3375 pellets mounted in parallel in a 7/16-inch double-ended stud package (TO-60). Typical DC characteristics of this device are identical to those of the 2N3375, except that the output capacitance is twice as

Fig. 7—Emitter and base contact areas.

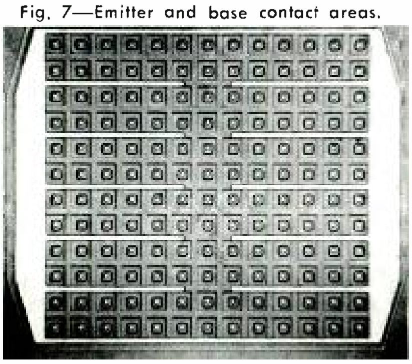


Fig. 8—Metal pattern.

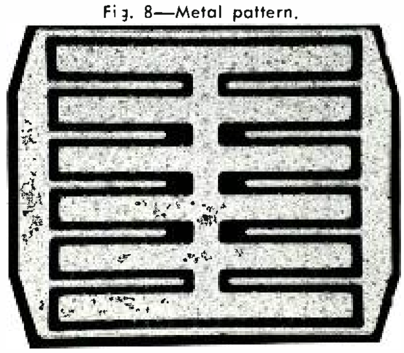
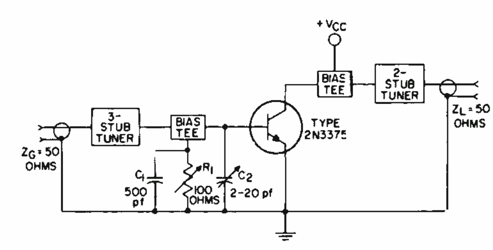


Fig. 9—RF Amplifier circuit for 2N3375 power-output test.



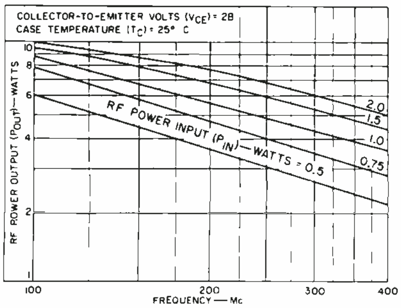


Fig. 10—Typical operation characteristics of 2N3375.

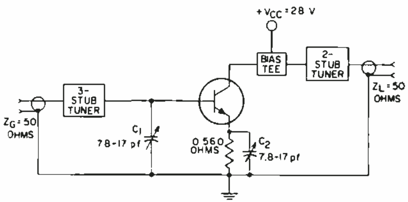


Fig. 11—Tuned-emitter 2N3375 power-output test circuit.

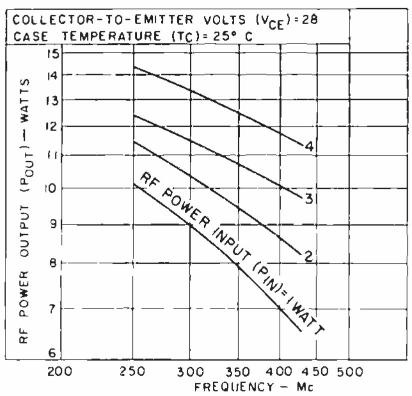


Fig. 12—Typical operation characteristics of 2N3733.

high. The RF performance of the 2N3733 was measured in the tuned-emitter circuit shown in Fig. 11. Curves of typical high-frequency performance are shown in Fig. 12. For an input power of 4 watts, power output was a minimum of 10 watts at 400 Mc/s and typically 14.5 watts at 260 Mc/s.

Variations of this overlay concept have been introduced which use emitter geometries other than squares. As a result of improvements in RCA photomask fabrication techniques and photolithographic technology, devices employing tighter tolerances and smaller geometries than the 2N3375 can now be fabricated. In developmental type TA-2658 (now commercial 2N3866) the overlay concept and technology have been extended to provide a geometry in which the emitter sites are only 0.15 mil wide. This device, which is intended for UHF driver applications, has 16 emitter sites 0.15 mil wide by 2 mils long. The ratio of emitter periphery to emitter area is better than that of the 2N3375 by a factor of two; as a result, the frequency response of the device is further improved. A photograph of a metalized TA2658 is shown in Fig. 13. Although the fabrication steps on this device are similar to those of the 2N3375, more than 4,000 pellets can be processed on each wafer because the pellet size is only 15 mils square.

The DC and UHF parameters of the TA2658 are shown in Table II. Typical high-frequency performance characteristics are shown in Fig. 14. The device has a minimum gain of 10 db at 400 Mc/s for 1 watt of output power. The device performance capability illustrated by these curves is well above the 400-Mc/s specification.

CONCLUSION

The significance of these devices is the availability of silicon transistors which result in high-power UHF operation far beyond that of previous state-of-the-art devices. As mentioned previously, prior to the development of the RCA 2N3375 the best commercially available RCA transistors were capable of power outputs of 30 milliwatts at 500 Mc/s. It is anticipated that further development of the overlay transistor structure will produce new generations of devices capable of delivering high output-power levels at frequencies greater than 1 Gc/s and will result in significant advances in semiconductor devices.

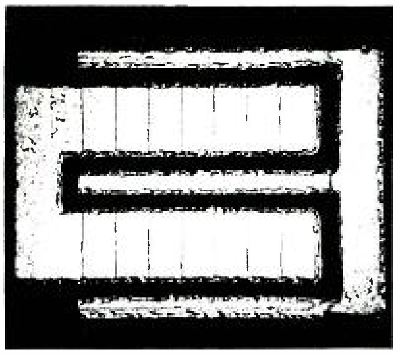


Fig. 13—Photograph showing metalized pellet for RCA-Dev. No. TA2658.

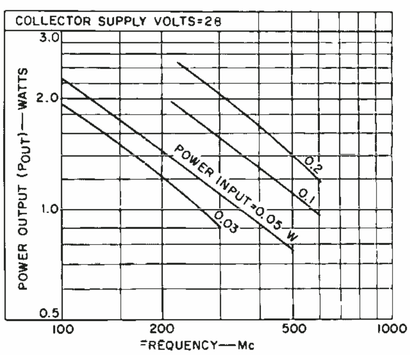


Fig. 14—Typical operation characteristics for TA2658.

TABLE II—Electrical Characteristics, TA-2658

$V_{CEO(SUS)}$	I_C = 5 mA, I_B = 0	30 V min.
$V_{CER(SUS)}$	I_C = 5 mA, R_{BE} = 10Ω	50 V min.
BV_{CBO}	I_C = 100 μA, I_E = 0	55 V min.
I_{CEO}	V_{CE} = 30 V, I_B = 0	20 μA max.
BV_{EBO}	I_E = 100 μA, I_C = 0	3.5 V min.
$V_{CE(SAT)}$	I_C = 100 mA, I_B = 20 mA	1.0 V max.
C_{ob}	V_{CB} = 30 V, f = 1 Mc/s	3.0 pF max.
P_{out}	f = 400 Mc/s, V_{CC} = 28 V, P_{in} = 0.1 W	1.0 W min.
	Eff. = 40% min.	

Case Temperature, 25°C Unless Otherwise Specified

ACKNOWLEDGMENT

The authors gratefully acknowledge the many contributions made by various engineering groups in EC&D to the development of the overlay transistors. Special recognition is due R. Duclos, G. Gilbert, and S. Matyckas.

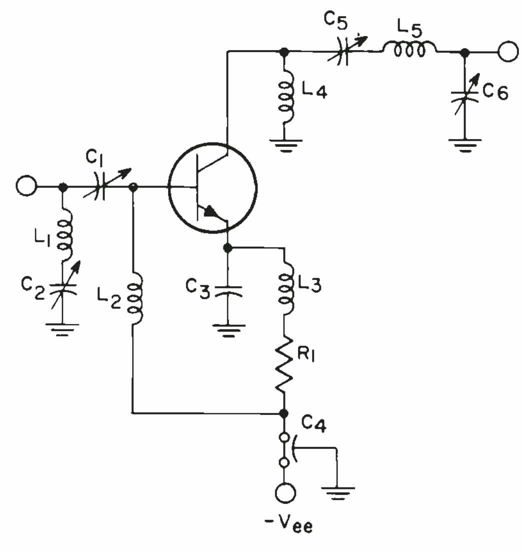


Fig. 15—Tuned-emitter TA2658 power-output test circuit (400 Mc/s).

VERSATILE 20-CUBIC-FOOT ULTRA-HIGH-VACUUM CHAMBER

This versatile 20-ft^3 ultra-high-vacuum chamber system was designed, fabricated, and tested by the RCA Service Company, and is currently available from the RCA Service Co. either as a complete system or as individual components. This new equipment operates consistently in the low 10^{-10}-torr range—with all experimental apparatus in place and with a very brief bakeout. The vacuum chamber can be loaded, sealed, pumped out, baked, and made ready to experiment within 24 hours. With somewhat longer bakes, it achieves vacuum levels of 10^{-11} torr; with no bakeout, it can reach vacuum in the 10^{-10} torr range after several days of pumping.

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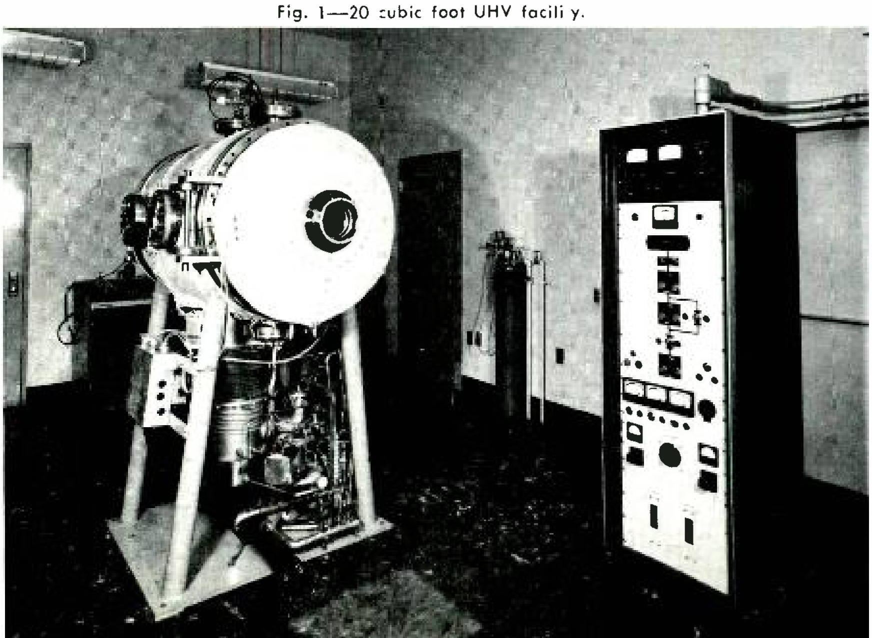
The performance of the vacuum system (Fig. 1) is shown in Fig. 2; these values were achieved with a bakeout of 250°C. Note that the chamber can achieve a vacuum, unbaked, on the order of 7×10^{-10} torr in 18 hours, and 1 to 2×10^{-11} torr after 72 hours. Values shown were obtained with all test equipment attached to the chamber. This equipment included two 5-inch bakeable glass windows, one all metal push-pull fixture with a 2-inch stroke, one electrical power feedthrough plate with twenty-one 30-ampere conductors, one instrumentation feedthrough plate with 120 conductors, and an ionization gauge feedthrough plate with two ionization gauges.

[EDITOR'S NOTE: *Ultra-high vacuum* is defined by the American Vacuum Society as the range of pressures below 10^{-9} torr. The *torr* is defined as the pressure necessary to support a column of mercury 1mm high. It is named for the 17th-century vacuum pioneer Evangelista Torricelli and is now the standard unit in vacuum technology.]

The vacuum system (Fig. 3) includes a 10-inch diffusion pump and a full fractionating unit featuring a split casing, with the top half welded directly to a combination water and liquid-nitrogen baffle which, in turn, is welded to the vacuum chamber. Several advantages are gained by this mounting technique; in particular, the organic *O*-ring seal for the diffusion pump is placed below the high vacuum portion of the pump. As a result, the outgassing of the *O*-ring does not become a factor in increasing the gas loads at ultra-high vacuum or contaminating the residual gas in the ultra-high-vacuum chamber volume. Should the diffusion pump flange be located elsewhere, a metal gasket seal would be required. Also, by welding the two baffles together, and then to the vacuum chamber, two sets of flanges and the accompanying flange sealing problems are eliminated.

Final manuscript received January 15, 1965.

Fig. 1—20 cubic foot UHV facility.



In this system, the main diffusion pump is backed by another 2-inch diffusion pump which, in turn, is backed by a 15 ft^3/min vacuum roughing pump. The plot in Fig. 4 indicates the Dow Corning DC-705 vacuum pump fluid used in both these pumps has an extremely low vapor pressure.

The water baffle is utilized as a refrigerated baffle with the operating temperature held below 0°C. This technique results in the capability of obtaining ultra-high vacuum while keeping the liquid nitrogen trap at ambient temperatures.

VACUUM CHAMBER

The horizontal vacuum chamber pictured in Fig. 5 has a 30-inch inside diameter and is 46 inches in length. Each end of the cylinder is provided with a hinged full diameter door. All ten penetrations into the chamber, with the exception of the diffusion pump penetration, are 5-inch metal gasketed bolted flanges. This feature allows complete freedom in arrangement of feedthroughs for a particular experiment. A detail of the metal gasketed flange seal is shown in Fig. 6. This seal was designed and developed by RCA Electronic Components and Devices and is currently being marketed under the flange part number J-1913 series. The large diameter doors are also metal gasket sealed and utilize a modification of the same design principle. This technique eliminates the need for the organic seals, previously used in all known designs on doors of this size. Although the use of this concept in large diameter bakeable ultra-high vacuum seals is initially more expensive, because of its accurately machined sealing surfaces, the cost is offset by eliminating the need of a large refrigeration system to refrigerate the organic *O*-ring and thereby reduce the outgassing load. In addition, the last major source of organic contaminants to the ultra-high vacuum chamber work space, is eliminated. In previous designs, utilizing the refriger-

D. L. SWARTZ received a BS and MS in Ceramic Engineering from Alfred University. He joined RCA Electron Tube Division in 1953 as a Development Engineer. After completing a three year military leave of absence in 1958, Mr. Swartz returned to RCA Service Company as a Systems Engineer and was assigned to the C-Stellarator program. Since this time he has participated in numerous projects involving environmental simulation in the areas of cryogenics, vacuum, and solar. He is presently Manager of Solar Simulation Systems for the Nuclear & Scientific Services Department.

RICHARD BOBO studied mechanical engineering at Trenton College Evening School, and has been employed by RCA since 1959. Prior to his current assignment, he performed work with solar simulators, cryogenic equipments, and various types of ultra-high-vacuum pumping systems and vacuum chambers. Included in these efforts has been the responsibility for field installation and environmental testing for the C-Stellarator Program, the RCA Space Center and the Helium Liquifier and Environmental Chamber for NASA, Langley. Mr. Bobo is currently Installation and Planning Engineer with responsibility for assembly and test of two extremely-high-vacuum chambers scheduled for delivery to NASA.

ated organic *O*-ring concept, two major problems were encountered. One was the necessity to cool the *O*-rings during bakeout to prevent permanent deformation with its accompanying high vacuum leakage problems, and the other was a heavy ice buildup in the refrigerated seal area when the chamber was in use. Both have been eliminated by the new design.

The vacuum chamber is constructed of Type 304L Stainless Steel with all welds made with the metal-inert-gas process externally and the tungsten-inert-gas process internally. The interior of the chamber, including the welds, is ground flat and smooth to a 120-grit finish. Model supports are welded into the interior of the vacuum chamber in eight locations equally spaced about the chamber volume. Each model support is capable of supporting a 500-pound load in any direction.

BAKEOUT

Ultra-high vacuum is usually achieved through reduction of the gas load or increasing the pumping speed of the system, or both. Principal sources of the gas loads consist of outgassing of the adsorbed gases of the vacuum chamber and system in the high vacuum portion together with "in-leakage" to the system and from the pumping media (i.e., back diffusion and back streaming, etc., from diffusion pumps). Another gas load source, which cannot be considered here, is that of the test specimen.

In-leakage, as a gas source, can be eliminated through the use of properly designed vacuum seals and metal joining techniques discussed previously. Availability of highly sensitive helium-mass-spectrometer vacuum-leak detectors assist the designer and fabricator in assuring that a vacuum system is leak tight.

Similarly, the use of modern design techniques can, for all practical purposes, eliminate gas loads from the pumping media. Very low vapor pressure diffusion pumping fluids, coupled with anti-migration, multiple bounce, cryogenically cooled traps, can reduce this source of gas load to immeasurable quantities.

When the control, described above, is exerted over two of the sources of gas, only outgassing of the adsorbed gases on the walls of the vacuum system exists as a major gas source. Utilization of materials with extremely low vapor pressures—in particular, metals, vitreous ceramics, glasses, and suitable metallic alloys—requires that a designer need only consider removal of those gases and contaminants on the surfaces exposed to the vacuum environment.

The following formula is an approximate expression for the outgassing for metals:

$$Q_0 = C_1(\exp[C_2/TC]) - \frac{2}{T}$$

where Q_0 = outgassing rate, torr-liters/second, T = absolute temperature, °K, and C_1 and C_2 = constants dependent on the material.

This relationship shows that the outgassing rate can be greatly enhanced by increasing the temperature of the walls of the vacuum chamber. By holding vacuum system walls at elevated temperature for many hours and pumping gases from the system, ambient outgassing rate can be appreciably reduced. Theoretically, it should be possible to continue this bakeout of the vacuum system walls until all gas has been removed. Practically, this is not presently possible, nor is it required. However, it is possible to reduce the outgassing rate of adsorbed gases by factors of 10^5 or 10^6 with high-temperature bakeouts (450°C to 500°C), and somewhat less at lower bakeout temperatures of 200°C to 250°C. Well-accepted rates for clean 300-series stainless steel are:

unbaked:	2×10^{-9} atm-cm^3/sec/cm^2
baked @ 250° C:	5×10^{-12} atm-cm^3/sec/cm^2
baked @ 450° C:	5×10^{-15} atm-cm^3/sec/cm^2

The formula also suggests that reductions of the wall temperature below ambient will also reduce the outgassing

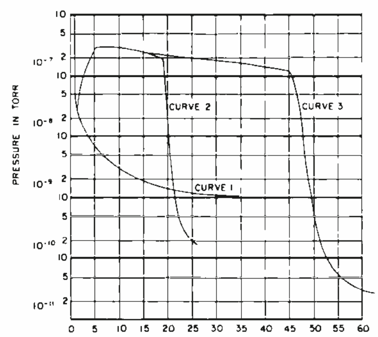


Fig. 2—Typical performance curves for 20 cubic foot UHV facility. Curve No. 1 is unbaked performance, Curve No. 2 is 15-hour bakeout performance, and Curve No. 3 reflects typical results with an extended bakeout of the system.

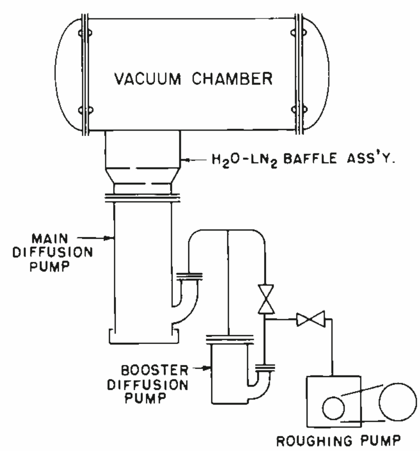


Fig. 3—Vacuum system schematic.

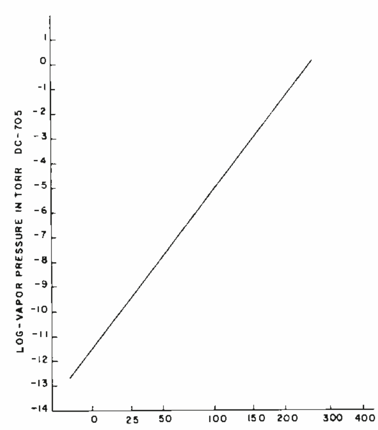


Fig. 4—Vapor pressure curve for DC-705 diffusion pump fluid.

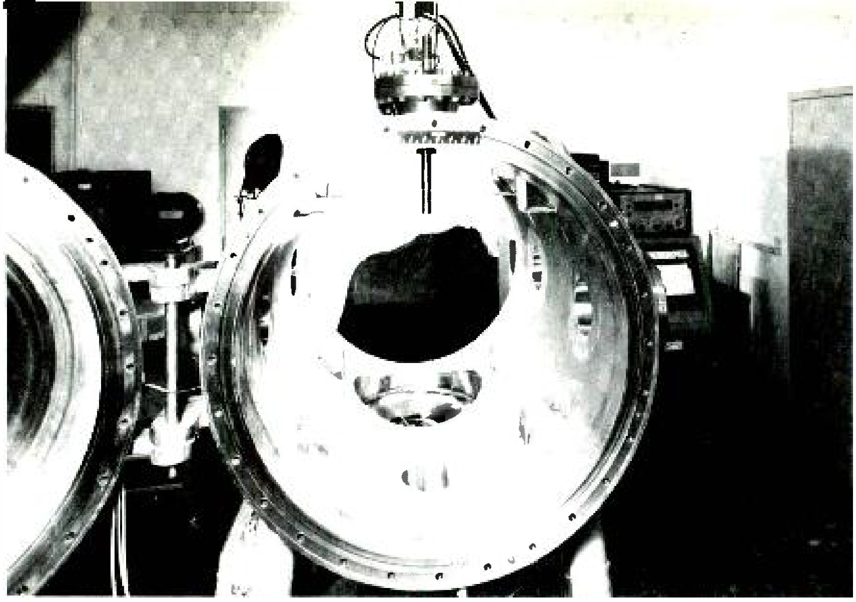


Fig. 5—Vacuum chamber.

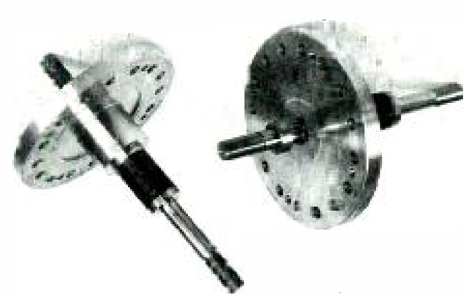


Fig. 7 — Bakeable all-metal push-pull mechanism with two-inch stroke.

rate significantly. Should the absolute temperature be reduced from ambient to 5°K, the out-gassing rate diminishes by about 10^{100}, a considerable reduction.

For this particular vacuum system, a bakeout temperature of 250°C is utilized. This choice is based on the balancing of the factors of the eventual facility use by the operator, the requirement to utilize glass windows, power feedthroughs, instrumentation feedthroughs, and other hardware which will not normally withstand continued use at elevated temperatures above 300°C. This could only be accompanied by special features including gold gaskets vs. aluminum, etc., and practical aspects, such as the time involved in performing a bakeout to achieve ultra-high vacuum for each experiment. Higher temperatures require rather longer periods of time to heat and cool the vacuum system. This reduces the total useful operational time available.

A combination heater-insulation blanket, initially shown in Fig. 1, was especially designed for use in baking out the vacuum chamber described above. Three bakeout circuits are used: one for the chamber body and end bells, one for the liquid nitrogen trap, and one for the nine 5-inch nozzle penetrations. Each of the nine nozzle penetration heater caps was designed to have the same heater capacity per unit area so that one controller, with thermocouples on each of the nine nozzles for monitoring of the temperature, could be utilized.

Once the vacuum chamber has been opened, the experiment loaded, and the chamber resealed, a typical bakeout procedure is as follows: 1) Heat the chamber to 250 °C, in increments of 50 °C; pause at each 50 °C jump to assure uniform heating over the three circuits; 2) once 250°C is attained, hold this temperature for a minimum of 12 hours and then turn off all heaters.

The insulating blanket allows the chamber to cool uniformly to room temperature over a period of approximately 12 hours. After outgassing of the vacuum inonization gauges, vacuum readings as low as the 10^{-11} torr range will be achieved. The ultimate pressure is a function of the payload under test and its outgassing properties.

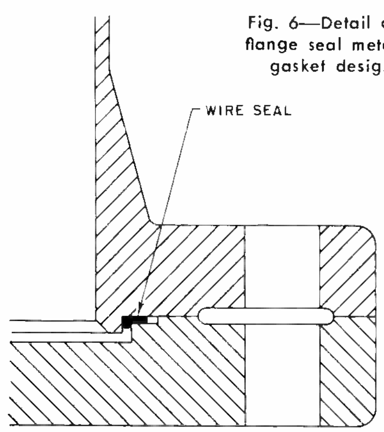


Fig. 6—Detail of flange seal metal gasket design.

VERSATILITY FEATURES

Modern laboratories desire versatile equipment when dealing with ultra-high vacuum as a tool. The best example of this facility's versatility is its fast response during pumpdown and the ability to achieve ultra-high vacuum with relatively high gas loads.

The other feature particularly desirable when considering capability in utilizing an ultra-high vacuum system, is the ability to transmit mechanical, optical, electrical and electronic signals into and out of the vacuum chamber. Figs. 7, 8, 9, and 10 show some of the special penetration assemblies available for use with this facility. In addition, liquid nitrogen shrouds, liquid or gaseous helium shrouds, bakeable coaxial feedthroughs, and power and thermocouple feedthroughs are readily utilized at the convenience of the operator at the facility.

Fig 8—Bakeable UHV five-inch windows, utilizing optical quality glass are supplied by ECD in Lancaster, Pa. Spectral transmission from 3,000 to 30,000 angstroms

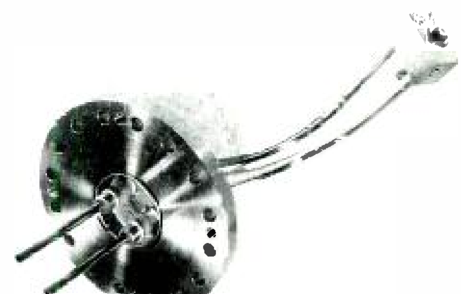


Fig. 9—Bakeable UHV high power feedthrough with water cooled capability of 3,000 amperes at 5,000 volts.

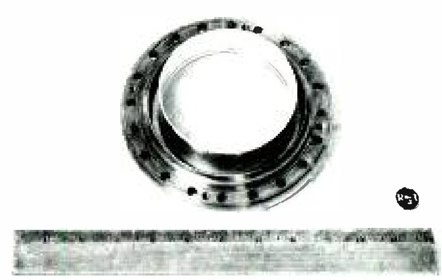


Fig. 10—Four-inch sapphire window with spectral transmission from 2,000 to 50,000 angstroms.

LASER VOICE AND VIDEO COMMUNICATIONS

Applying the GaAs Room-Temperature Injection Laser and the GaAs Electro-Optic Crystal

For communications, optical frequencies offer many advantages over radio frequencies — more channels, long-distance transmission with less power, and employment of wideband modulation methods. Described first herein is the design of an experimental voice communications system using a GaAs room-temperature injection laser (developed at RCA Laboratories). Then discussed is development of a TV communications system using very-high-resitsivity GaAs crystals (developed by RCA Electronic Components and Devices) as practical modulators for laser beams at TV bandwidths. In conclusion, modulation methods are compared.

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Applied Research, DEP, Camden, N. J.

For communications purposes, the electromagnetic wave spectrum may be divided into two broad regions with a vague boundary in the vicinity of 1 Tc/s (*teracycle*, 10^{12} c/s). In terms of wavelength, this boundary corresponds to a few tenths of a millimeter and is thought of as lying between the ultramicrowave region and the infrared region. The so-called *radio frequencies* below this boundary can be generated by conventional electronic techniques, as high-efficiency, high-intensity, coherent electromagnetic waves. But, the generation of high-intensity, coherent waves *above* 1 Tc/s has, until recently, been limited by an inability to manufacture electronic cavity resonators with dimensions compatible with the short wavelengths involved. The solution to this problem has been achieved through the generation of high frequencies by natural atomic resonances, the outstanding example of which is the laser[1]—at this date, available in several forms: gas, crystal, and semiconductor diode.

Thus, possibilities for communications at frequencies above 1 Tc/s now exist. With its ability to generate both coherent and high-intensity radiation at optical wavelengths, the laser provides good reasons for using an optical carrier wave instead of a conventional radio wave for certain applications. For example, more communications channels are possible at optical frequencies, and the wider channel bandwidths available allow wideband modulation methods to be easily employed. Also, the inherent narrow beamwidth of the emitted laser radiation makes longer ranges possible with less power than required by conven-

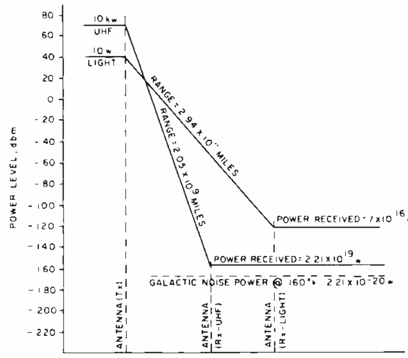


Fig. 1—VHF-Light power level comparison.

tional systems. This is especially true for communications in space at astronomical distances. While conventional UHF and laser systems are competitive at communication ranges of 50 million miles (the distance between Earth and Mars)[2], at much greater distances (say a billion miles), the performance of a laser system far *exceeds* that of the conventional one. An illustrative comparison between the two systems is provided by the power level diagram of Fig. 1. Of course, the narrow laser beamwidth, which is an important factor in establishing this advantage, also places severe tracking requirements on the system.

Typical applications of the laser include: 1) laser voice and TV communications; 2) laser radar devices, such as a hand-held laser radar for the blind, a laser radar for airborne refueling, a low-altitude laser altimeter, and a space vehicle docking radar; 3) a laser transmitter for target practice systems; and others. *All of these applications have much in common, and many design procedures are basic to each one.* Implementation of an optical communications system requires an understanding of the properties of laser materials, and the creation of devices with which to modulate and detect the optical carrier. To illustrate the basic principles involved,

Final manuscript received March 18, 1965.

Fig. 2—Current input to and light output from GaAs laser diode. Horizontal time scale is 100 ns/div. Vertical scale in the lower trace is 10 A/div. and represents the diode injection current. Vertical scale in the upper trace is 500 mW/div. and represents the light pulse emitted from one end of the laser diode.

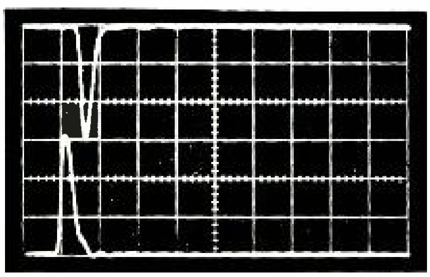


Fig. 3—Light output power vs diode current.

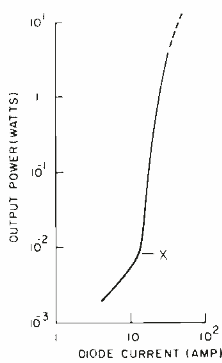
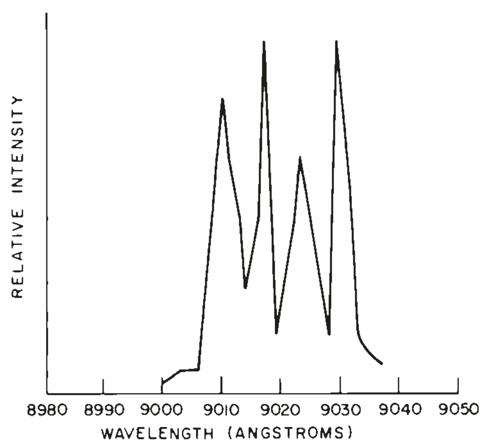


Fig. 4—Emission spectrum of room-temperature GaAs laser diode.



two of these systems—the RCA Injection Laser Voice Communications System and the RCA Electro-Optic TV Communications System—are described in this paper.

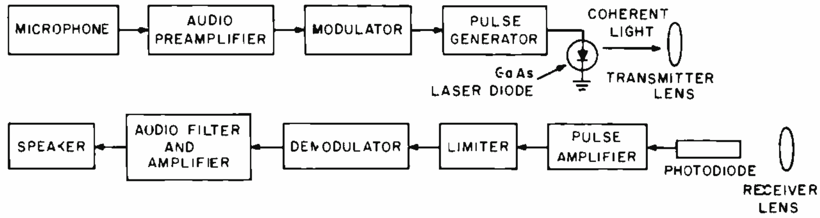


Fig. 6—Major components of laser communication system.

INJECTION LASER VOICE COMMUNICATIONS

A highly efficient current-pumped GaAs semiconductor diode that operates as an injection laser at room temperature has recently been developed at the RCA Laboratories.[3] This diode is typically capable of radiating a peak power of 1.5 watts at a peak injection current of 30 amperes. This performance is indicated clearly by the dual-beam oscilloscape traces in Fig. 2.[4] The lower trace represents the current input to the diode and the upper trace shows a multiplier-phototube response to light emitted from the output end of the diode. (The apparent delay of the light pulse with respect to the current pulse is due to electron transit time in the multiplier phototube used for detection.) While Fig. 2 illustrates the performance of a typical diode, some RCA diodes emit as much as 7 watts with the same injection current and as much as 30 watts with an injection current of 120 amperes.

Shown in Fig. 3 is the relationship between laser diode light output power and current. The neighborhood about point X on this plot, where the slope suddenly changes, represents the laser threshold of the diode. Above the threshold, the radiation is coherent; below the threshold, the radiation is substantially incoherent. For currents above point X, the laser output steadily increases until heating effects cause it to taper off.

The emission spectrum of a typical room-temperature GaAs laser diode is shown in Fig. 4. The spectrum consists of four longitudinal modes spaced approximately 6 angstroms apart. This is in agreement with the mode spacing calculated from the length of the Fabry-Perot cavity formed by the diode. In general, laser emission at room temperature occurs at about 9,020 angstroms, with a temperature-dependent shift of about 1.75 angstroms/°C, as shown in Fig. 5.

Operating the GaAs diode as a laser (i.e., above the point X in Fig. 3) rather than as an incoherent source offers three significant advantages: First, the quantum yield for a given power input to a light-emitting diode (i.e., the conversion efficiency) is greater when the diode is operated in the laser mode. Second, because the laser emits light in a narrow beam, its power output is concentrated in one direction, and, thus, the need for large collimating and collecting lenses is eliminated. A typical laser diode emits light in a fan-shaped beam approximately 3° by 10°. With moderately-sized lenses, this beam can be focused into a 2-milliradian diameter, thereby increasing the useful radiated power. The third advantage is derived from the spectral purity of the emitted laser radiation. The radiation is confined to a spectral bandwidth of about 20 angstroms (Fig. 4), which allows a narrowband optical filter to be used in front of the optical detector, considerably reducing background noise. (Although the spectral bandwidth is about 20 angstroms, an optical filter of 50 angstroms is used to allow for center frequency shifts due to temperature changes, as predicted by Fig. 5.)

These properties and advantages of the RCA GaAs room-temperature laser diode have made possible the implementation[4] of the simple, reliable voice communications system shown in Fig. 6. Pulse-frequency modulation (PFM) is used in this system because the power dissipation limits of the diode necessitate pulsed operation. A photograph of the complete prototype system is shown in Fig. 7. Excluding power supplies, microphone, and speaker, the physical size of the transmitter is 6 by 2.25 by 2.25 inches, while that of the receiver is 4 by 2.25 by 2.25 inches. The small size of the system is made possible by the absence of the refrigeration equipment needed for conventional laser diodes.

An analysis of the performance of a system such as that shown in Fig. 7 requires an investigation of photodetector dark current, preamplifier noise factor, received background shot noise power, received signal power, duty factor, amplifier bandwidth, modulation frequency, probability of error, atmospheric attenuation, and lens attenuation. Taking all these parameters into account, it can be shown that the required average transmitter power $\overline{P}_t$ for an injection laser voice communications system using a solid-state photodetector is:

$$\overline{P}_t = \frac{10B_m\sqrt{CFkT}}{\rho}\,\frac{\alpha\beta R^2}{A_r T_a T_o} \qquad (1)$$

where B_m = highest modulation frequency, c/s; C = shunt capacitance across photodetector load resistor, farads; F = noise factor of preamplifier; k = Boltzmann's constant, 1.38×10^{-23} joule/°K; T = temperature, °K; α = long angular dimension of emitted laser beam, radians; β = short angular dimension of emitted laser beam, radians; R = range, meters; ρ = responsivity of

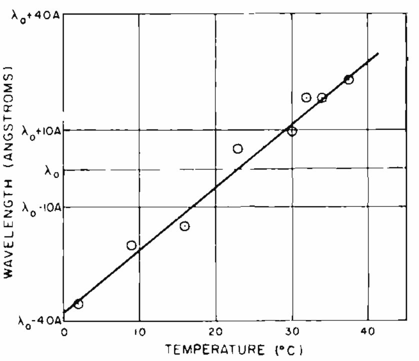


Fig. 5—Emission wavelength vs temperature for GaAs diode.

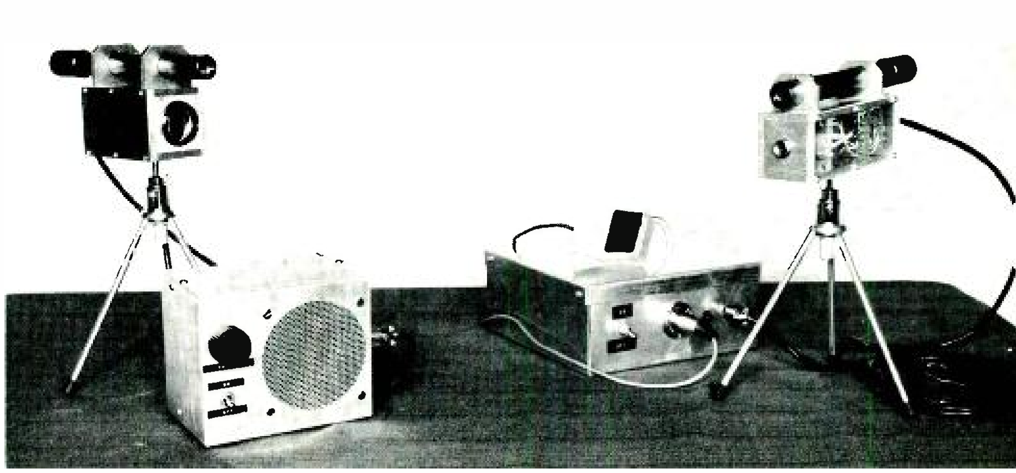
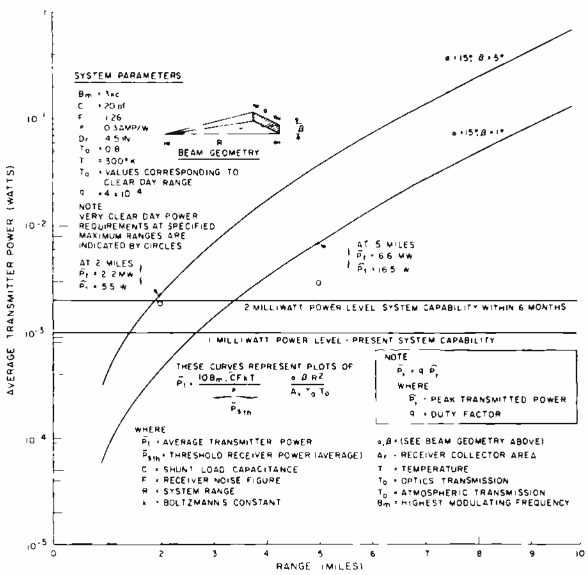


Fig. 7—Photograph of the system shown schematically in Fig. 6. The transmitter with its power supply and microphone in on the right. The receiver with its power supply and speaker is on the left.

photodetector, amperes/watt; A_r = receiver collector area, square meters; T_a = atmospheric transmission; and T_o = optics transmission.

From Eq. 1, curves relating required transmitter power to range have been plotted in Fig. 8 for some typical system parameters. Also shown in Fig. 8 are present and future transmitter power output capabilities.

Fig. 8—Average transmitter power vs range.



ELECTRO-OPTIC TV COMMUNICATIONS SYSTEM

A practical light modulator that allows the realization of modulation bandwidths of 5 Mc/s or higher is the electro-optic crystal modulator shown in Fig. 9, taken from Ref. 5. The electro-optic crystal is placed between a polarizer and an analyzer. The polarizer permits only light polarized in one plane to reach the crystal. As the plane polarized light passes through the crystal, it becomes elliptically polarized, the amount of ellipticity depending on the voltage applied to the crystal. Since the analyzer transmits light polarized in only one plane, the intensity of the light transmitted through the modulator depends on the ellipticity introduced by the crystal. Hence, the light beam is amplitude modulated in accordance with the voltage applied to the crystal.

The intensity of the light transmitted through the analyzer for a commonly used crystal orientation is:

$$I = I_o \sin^2\left(\frac{\sqrt{3}\,\pi\, rn^3\, lV \sin \omega t}{2\lambda d}\right) \quad (2)$$

where I_o = intensity of laser source, watts; l = length of crystal, meters; d = thickness of crystal (in direction of electric field, meters; n = index of refraction; r = electro-optic coefficient, meters/volt; λ = wavelength of laser beam, meters; ω = frequency of the modulating signal, radians/sec; and V = peak amplitude of modulating voltage, volts.

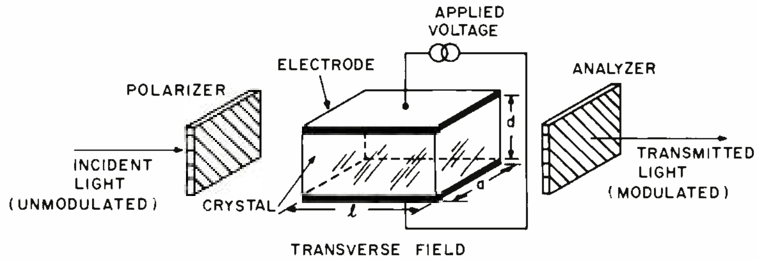


Fig. 9—Electro-optic modulator.

Eq. 2 shows that the peak-to-peak drive voltage needed to achieve 100% modulation is:

$$V_{\lambda/2} = \frac{\lambda d}{\sqrt{3}\, n^3\, rl} \quad (3)$$

This voltage is known as the half-wave voltage because it results in a 180-degree shift in the plane of polarization. Substituting Eq. 3 into Eq. 2 gives:

$$I = I_o \sin^2\left(\frac{\pi V \sin \omega t}{2V_{\lambda/2}}\right) \quad (4)$$

A plot of this equation, Fig. 10, indicates that the intensity of the modulated beam varies at twice the modulation frequency. This is a consequence of I reaching a maximum twice for every cycle of the modulating voltage; that is, I is at a maximum when $\sin \omega t = 1$, and also when $\sin \omega t = -1$.

To eliminate this "double frequency" effect, the electro-optic modulator must be biased either electrically or optically. The latter is easier and can be accomplished by placing a quarter-wave plate, properly oriented to obtain circularly polarized light, between the polarizer and the crystal. For this case, the transmitted intensity is:

$$I = I_o \sin^2\left(\frac{\pi V \sin \omega t}{2V_{\lambda/2}} + \frac{\pi}{4}\right) \quad (5)$$

The plot of this equation, Fig. 11, shows that the transmitted intensity is $I_o/2$ when the modulation voltage is zero and that 100% modulation is achieved when the peak-to-peak modulation voltage is equal to $V_{\lambda/2}$.

It can be shown that the percent modulation m is:

$$m = \left[\sin\left(\frac{\pi V \sin \omega t}{V_{\lambda/2}}\right)\right] 100 \quad (6)$$

This equation is plotted in Fig. 12, where it is evident that a reasonably high percent modulation can be achieved even

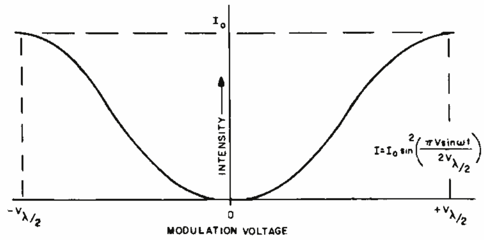


Fig. 10—Intensity vs modulation voltage.

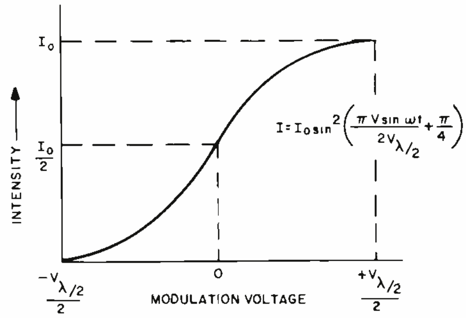


Fig. 11—Intensity vs modulation voltage with $\lambda/4$ plate.

W. H. Hannan

Dr. J. Bordogna

W. J. HANNAN graduated from the RCA Institutes in 1951 and was hired by RCA as an engineer in the Industrial Products Division. He contributed to the design of the RCA industrial television camera chain, a general purpose system used to monitor industrial operations, and the "Walkie Lookie," a portable television system used by NBC to televise events not readily accessible with standard broadcast equipment. He received the BS in EE from Drexel Institute (evening college) in 1954. He was awarded a Sarnoff Fellowship which he used to obtain the MS in EE from the Polytechnic Institute of Brooklyn. Mr. Hannan has been with the DEP Applied Research group since 1956. His experience includes the design and development of transistor television circuits, digital communication receivers, digital data-processing equipment and optical communication systems. He taught a transistor circuit theory course at RCA and at Rutgers University. He was project leader on: a program to determine how the parameters of a communication link between an airborne television sensor and a ground station affect the ability of a photointerpreter to detect and recognize targets; an analysis of the trade-off between signal-to-noise ratio and resolution in television systems; development of an electro-optical reading machine for Russian technical journals; and an experimental program to determine the feasibility of using a laser for measuring the velocity of a spacecraft. He is currently project leader on a program to assess solar-pumped lasers for deep space communications. Mr. Hannan was chairman of the Philadelphia section of the IEEE Group on Circuit Theory during 1963.

DR. J. BORDOGNA received the BSEE degree from the University of Pennsylvania in 1955, graduating with distinction. Upon graduation he entered the Navy, following his release from active duty in 1958, joined RCA in the DEP Applied Research group. In 1959, on a leave of absence, he studied on a Whitney Fellowship at MIT, receiving the SM degree in 1960. On another leave of absence in 1961, he attended the University of Pennsylvania on a Moore School Fellowship, his PhD in 1964. Currently he is the Winterstein Assistant Professor of Engineering at the University. Dr. Bordogna's research includes work on synchronization problems in FSK receivers, Q multipliers, development of FM modulators, design of automatic phase-control circuits, design of circuits for a magnetic-recording machine used to modify sonar frequencies for video displays, design of low-frequency antennas, development of breadboard designs of phase-shift-keyed communications system, and development of an electronically variable delay line for correcting random jitter in a video tape-recording system. In addition, he has completed theoretical studies of FM variable-bandwidth communications systems for tropospheric scatter propagation, applications of lasers, and an analysis of the RANGER moon probe television subsystem. He also participated in demonstrating the wideband modulation properties of GaAs and in the development of the wideband GaAs electro-optic modulator. Dr. Bordogna is a member of Tau Beta Pi, Eta Kappa Nu, Sigma Xi and the IEEE, and is co-author of a textbook entitled "Electric Networks—Functions, Filters, Analysis" (to be published December 1965 by McGraw-Hill Book Co., Inc.).

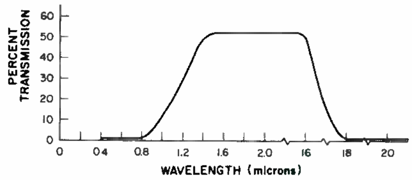


Fig. 13—Transmission characteristics of GaAs crystal dimensions 1 cm x 3 mm x 3mm.

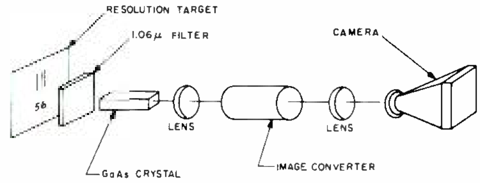


Fig. 14—Experimental setup for investigating transparency of GaAs.

when the modulation voltage is considerably less than $V_{\lambda/2}$. For example, 80% modulation is achieved when $V/V_{\lambda/2} = 0.3$.

There are many crystals which exhibit the electro-optic effect, and they all have their good and bad features. Until recently, GaAs showed little potential as an electro-optic modulator because the low resistivity of available crystals prevented application of the high electric fields required for a reasonable per cent modulation. However, research efforts by RCA's Semiconductor Materials Research Group in Somerville, N. J. resulted in the development of GaAs crystals having very high resistivity, on the order of 1 megohm-cm. This technical breakthrough converted GaAs from a laboratory curiosity into a practical device for electro-optic modulation.

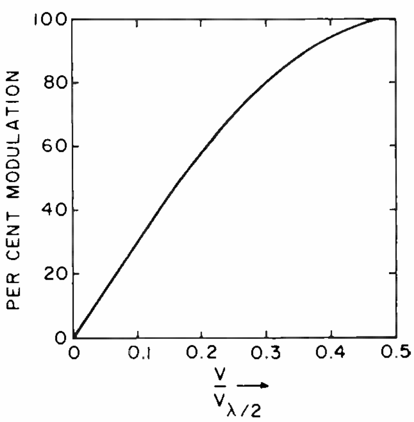


Fig. 12—Percent modulation vs V/V λ/2.

The transmission characteristics of a GaAs crystal are given in Fig. 13. In this graph the transmission loss in the spectral band from 1.4 to 16 microns is negligibly low, practically all the attenuation being due to reflection at the ends of the crystal. Therefore, with antireflection coatings on its ends, the transmission of the crystal can be increased to about 90%.

To investigate the quality with which an RCA-developed GaAs crystal passes an image at ir wavelengths, the experiment shown in Fig. 14 was performed. Light impinging on a standard resolution chart illuminated the numerals *56*, and some resolution lines were ultimately imaged on photographic film after passing through a GaAs crystal. The image converter was used to convert the ir image to a visible one. The results of this experiment are given in Fig. 15, which shows a photograph of the image at the output face of the crystal. (The crystal used in this experiment was the same as that used in the TV experiments to be described below.) It is evident from Fig. 15 that GaAs is transparent at infrared frequencies with good transmission. Note the clarity of the numerals and the sharpness and definition of the resolution lines.

In summary, a careful review of available electro-optics crystals has revealed that a GaAs crystal is a good choice for electro-optic modulation because it possesses the following qualities:

1) can be grown 5 cm long
2) has reasonably low drive requirements
3) is transparent in a spectral range where high power lasers are available
4) is nonhygroscopic
5) will not develop strains under normal handling

Fig. 15—Image of numerals seen through a GaAs crystal.

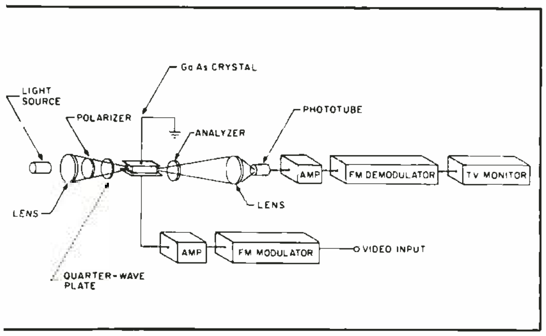


Fig. 16—Optical TV communications system.

6) does not require temperature control
7) does not require further materials research
8) has been used successfully to transmit 5-Mc/s TV pictures (see below)

Operation of an optical TV communications system with a GaAs electro-optic crystal has been successfully demonstrated using the configuration shown in Fig. 16. The crystal used in this system was 1 cm by 3 mm by 3 mm (the same crystal used in the experiment of Fig. 14). A tungsten lamp was used as a light source. The physical arrangement corresponding to Fig. 16 is shown in Fig. 17. In addition to the subcarrier modulation method indicated specifically in Figs. 16 and 17, baseband modulation was also tested. With baseband modulation, the video signal was simply amplified by the crystal drive amplifier (Fig. 18) and applied directly across the crystal. A photograph of the monitor presentation for this type modulation is shown in Fig. 19.

The "herringbone" background modulation in Fig. 19 is the result of a piezoelectric crystal resonance at about 500 kc/s. To eliminate this effect, the subcarrier modulation scheme of Figs. 16 and 17 was employed to shift the signal spectrum away from 500 kc/s. In this system, an Indian-head TV test pattern signal drives the FM subcarrier (5 Mc/s) modulator, the output of which is fed to the crystal drive amplifier (Fig. 18). The crystal drive amplifier applies the modulating voltage across the GaAs crystal through which the optical carrier is passing. The modulated light is detected by a 7102 multiplier phototube, demodulated, and displayed on the monitor. (Vestigial sideband FM modulation was actually used, with a deviation ratio of about 0.2 and most of the upper sideband filtered before the signal was applied to the GaAs crystal.) Fig. 20 is a photograph of the picture that appeared on the TV monitor when this type modulation was used. It is evident that no piezoelectric distortion appears in this picture. Another benefit derived from subcarrier modulation is the elimination of "flicker" noise caused by low-frequency fluctuations of the light source. This is to be expected, of course, since the FM spectrum is filtered in the receiver, eliminating all frequencies below about 10kc/s.

In the experiment of Fig. 16, the lower wavelength limit of the spectral bandpass was 0.9 micron, the bandgap absorption edge of GaAs. The upper wavelength limit was about 1.1 microns, the limit of significant response of the S-1 photocathode. A practical CW crystal laser source is available in this region—namely, yttrium-aluminum-garnet (YAG) doped with neodymium. This crystal emits coherent radiation at a wavelength of 1.06 microns. At this wavelength, the electro-optic coefficient and index of refraction of GaAs are 1×10^{-10} cm/volt and 3.34, respectively. Thus, since the crystal used in the experiment of Fig. 1 had a thickness of 3 mm and a length l of 1 cm, Eq. 3 predicts a half-wave voltage $V_{\lambda/2}$ of 4.7 kV. Tests conducted with peak-to-peak drive voltages as high as 800 volts (and signal spectra extending to 6 Mc/s) have verified the theoretical values of percent modulation given in Fig. 12.

Based on the properties of GaAs and the results of the preceding experiments, it can be concluded that a GaAs crystal is a practical device for modulating a laser beam at TV bandwidths. It is rugged, its drive requirements are reasonable, and optical alignment is not critical.

WIDEBAND MODULATION COMPARISON

Assuming that the usual steps are taken to minimize the noise factor of the optical TV receiver, over-all system performance depends primarily on the type of modulation employed. The choice of modulation method involves a compromise among required transmitter power, available bandwidth, minimum acceptable signal-to-noise ratio, and acceptable complexity of the modulation and detection circuits.

Modulation techniques which allow channel bandwidth to be traded for higher signal-to-noise ratio of the detected signal are referred to as wideband modulation techniques. These techniques are particularly advantageous for optical communication links because the spectral width of the unmodulated carrier is usually orders of magnitude wider than the bandwidth of the modulation signals and because extremely wide channel bandwidths are available. To show this improvement offered by wideband modulation methods, the performance of conventional analog and wideband modulation systems are compared below. (In order to maintain realism, the comparison is based on systems having identical transmitters and receivers, the only difference being the bandwidths needed to accommodate the different modulation schemes.) In this comparison, the relative performances of four different modulation methods are considered, namely, conventional pulse-code modulation (PCM), delta modulation, narrowband analog amplitude modulation (AM), and wideband analog frequency modulation (FM).

As a starting point for the comparison, the required signal-to-noise ratio must be specified. In this regard, subjective tests have shown that a signal-to-noise power ratio (*SNR*) of 30 dB will result in a TV picture that is subjectively noise free (i.e., a TV picture produced with a 30-dB *SNR* in a 5-Mc/s bandwidth and viewed at a "normal" distance of four times the picture height appears essentially noise free). Thus, the comparison is based on achieving the *SNR* needed to realize a noise-free picture.

Another factor of importance for the comparison is related to the fact that all modulation methods that achieve higher *SNR* at the expense of wider channel bandwidth (regardless of whether they employ analog modulation or digital modulation) suffer a threshold detection level below which performance deteriorates rapidly. To put this another way, the *SNR* with wideband modulation remains high (e.g., 30 dB) out to the range at which the threshold detection level is reached, then drops to an unusable value. On the other hand, with narrowband modulation, the *SNR* drops mono-

Fig. 17—Experimental optical TV communications system. Visible in foreground from left to right along the optical bench are: light source, polarizer, quarter-wave plate, focusing lens, transistorized electro-optic modulator (including crystal and drive amplifier), focusing lens, analyzer, and photomultiplier. Visible in background on shelf from left to right are: FM modulator, TV monitor, FM demodulator.

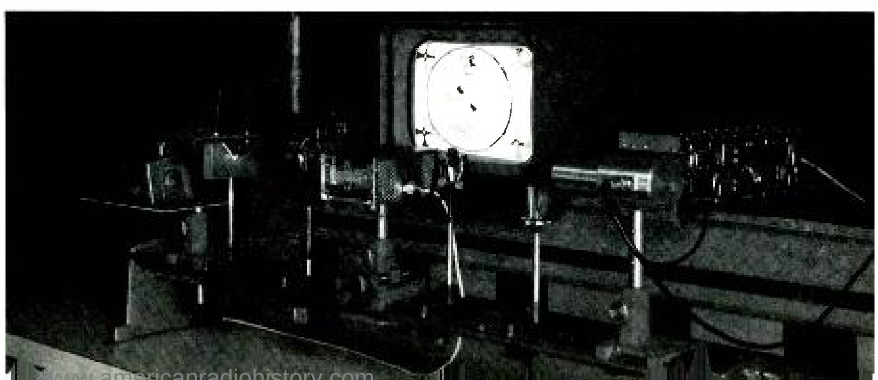


Fig. 18—Experimental transistorized electro-optic modulator. The electro-optic crystal is located at the center between the adjustable electrodes and is aligned lengthwise between the two light holes (through which the laser beam passes). The remainder of the circuitry comprises the crystal drive amplifier. Note the four 40256 output transistors mounted in heat sinks on insulating blocks to reduce output dissipative and capacitive losses.

tonically as range is increased. Thus, beyond the threshold detection level of a wideband system, the *SNR* of the narrowband system is much higher; but it is below the acceptable level for TV pictures.

For the comparison, the AM system has arbitrarily been chosen as the reference system. A plot of *SNR* versus *R* (range) for the AM system is given in Fig. 21. The range R is normalized to R_o, the maximum range for a noise-free picture. It is evident in this plot that the *SNR* of an AM system is inversely proportional to R^2 and that $R/R_o = 1$ corresponds to the range at which *SNR* is 30 dB.

For PCM and delta modulation, the *SNR* remains essentially constant (being determined by the quantizing noise) out to the threshold detection range, where it drops to an unusable value. For FM the wideband improvement over AM is realized out to the threshold detection range, after which the *SNR* drops to an unusable value just as in the cases of PCM and delta modulation. The threshold detection range R_t for these modulation methods can be shown to be:

$$\left(\frac{R_t}{R_o}\right)_{PCM} = 5.1$$

$$\left(\frac{R_t}{R_o}\right)_{DELTA} = 5.7$$

$$\left(\frac{R_t}{R_o}\right)_{FM} = 5.1$$

The results of the foregoing analyses are plotted in Fig. 21 along with the *SNR*-vs-range curves of the AM system. It is seen that all the wideband modulation methods provide a noise-free picture out to a much greater range than can be realized with amplitude modulation; that delta modulation provides about 10% greater range than either PCM or analog FM; and that PCM and analog FM provide equivalent performance.

The relative merit of different wideband modulation methods depends upon the desired output *SNR*. If an extremely high *SNR* is needed, say 50 dB or higher, then a wideband modulation method such as PCM, which increases *SNR* exponentially with bandwidth expansion, is undoubtedly the best choice. On the other hand, if an *SNR* of only 30 dB is needed (as in the optical TV system described above), other wideband modulation methods provide equal, or better, performance with less complex circuitry.

CONCLUSIONS

The development of the GaAs room-temperature injection laser diode by RCA Laboratories has enabled DEP Applied Research to design and demonstrate the feasibility of a practical voice communications system. The development of GaAs crystals with very high resistivity by the RCA Electronic Components and Devices Division has enabled DEP Applied Research to develop and demonstrate an optical TV communications system, establishing the GaAs crystal as a practical device for modulating laser beams at TV bandwidths. These developments represent long strides forward in taking the laser from an interesting item for laboratory study to a practical and widely useful device. Continued work along these lines should lead to diversified optical communications systems, mostly applied to the necessity of communicating across vast ranges in outer space. DEP Applied Research is currently in the process of applying the injection laser to the development of radar systems for a multitude of outer space and in-atmosphere uses.

ACKNOWLEDGEMENTS

The laser applications described above could not have been achieved without the effective teamwork which exists between the laser devices group headed by H. R. Lewis at the RCA Laboratories and the laser applications group of DEP Applied Research. Many individuals in these groups have made significant contributions in this area as evidenced in the list of references below. In particular, special mention must be given to G. C. Dousmanis, F. Hawrylo, A. Matzelle, H. Nelson, J. I. Pankove, T. E. Walsh, and J. P. Wittke of the Laboratories and to D. Karlsons, C. W. Reno, and T. E. Penn of Applied Research.

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Fig. 19—Picture obtained with baseband modulation.

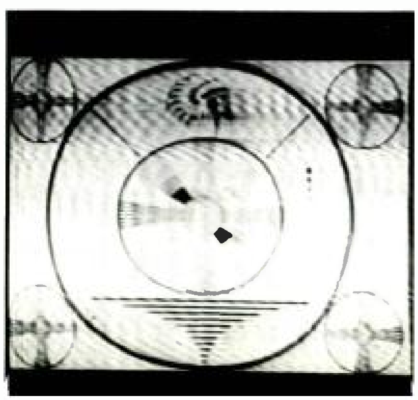


Fig. 20—Picture obtained with subcarrier modulation.

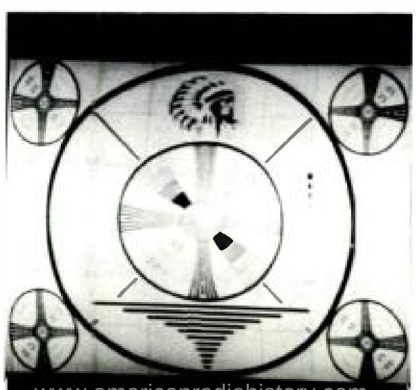
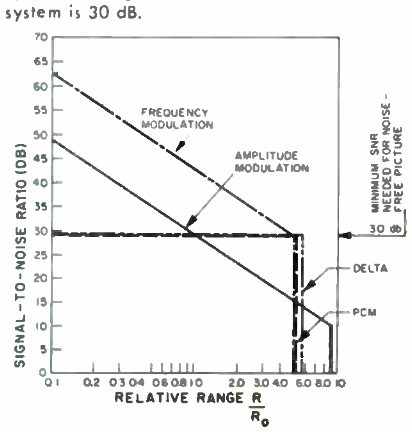


Fig. 21—Comparison of modulation methods. R_o is the range at which the SNR of the AM system is 30 dB.



A DEVELOPMENTAL WIRELESS BROADCAST MICROPHONE SYSTEM USING AN ULTRAVIOLET-LIGHT CARRIER

In many broadcasting situations (such as national political conventions) a wireless microphone is essential for on-the-spot audio coverage over a large area. While radio microphones currently fill this need, there are not sufficient channels for all broadcasters to use simultaneously without risking undesirable interference. As a solution, NBC is exploring a system consisting of a portable microphone-transmitter and remote receiver that uses ultraviolet light rather than a radio wave as a signal carrier. In progress to date, experimental equipment has worked successfully at 500-foot, line-of-sight ranges. Further work can probably solve present limitations on receiver sensitivity, which if materially increased could minimize the need for line-of-sight transmission, and further improve operation to make the system competitive with the radio microphone for many applications.

JARRETT L. HATHAWAY graduated from the University of Colorado in 1929 with a BSEE and that year joined the Development Engineering Group of the National Broadcasting Company. On a leave of absence from 1941-44, Mr. Hathaway served on faculty appointment at Harvard University where he participated in development of new systems of underwater sound detection and missile guidance. Returning to NBC in 1944, he participated in a government sponsored project on high-altitude night photography. Appointed NBC Staff Engineer in 1947, he has been involved in nearly all phases of television and radio engineering. Several years were devoted part-time to patent litigation consultation. Mr. Hathaway has been granted 34 U.S. Patents. He is a Senior Member of IEEE, and a Member of Eta Kappa Nu.

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During recent years cable-less radio microphones have seen wide and increasing usage because of the inherent freedom of movement they offer as compared to ordinary cable-connected microphones. With the wireless system there is no cable to drag, trip on, or tangle. Furthermore, when a sizeable area such as a convention hall must be covered with sound pickup from any conceivable spot, the use of wire connections is impractical. Increased application of radio microphones has recently been toward the higher frequencies, including those around 160 and 450 Mc/s. These frequencies generally provide improved results as compared to those in the 26-Mc/s range because of better antenna efficiencies and lower ambient noise levels. In all of these frequency ranges, however, there is not a sufficient number of channels for all broadcasters to completely replace the wired circuits without incurring interference. Thus, if full potential of the cable-less microphone is to be exploited, some system of supplementing radio may be necessary in the future.

NBC is conducting a continuing developmental program to perfect techniques other than radio transmission for creation of a cable-less microphone. The medium of transmission is light. To avoid as much interference as possible from intense visible lighting, a portion of the ultraviolet, or black-light spectrum is employed. Infrared has also been considered, but is not as promising because of the great amount of infrared emanation from large incandescent lamps. Ultraviolet is, of course, at a serious disadvantage in long-distance transmissions whenever precipitation, haze, or smoke prevail; however, for relatively short ranges, such as 500 feet, the advantage of reduced competition from powerful light sources outweighs the better propagation at longer wavelengths.

Final manuscript received October 5, 1964

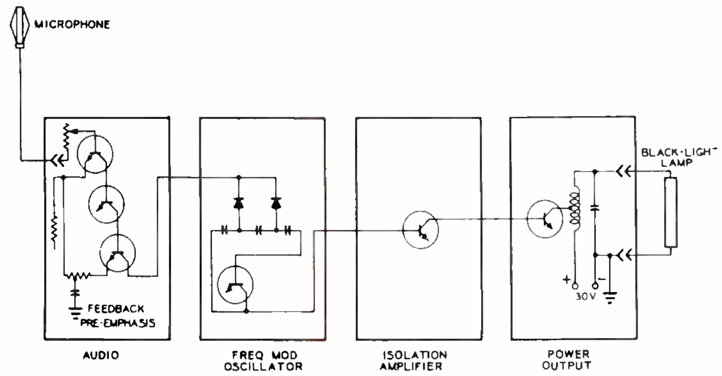


Fig. 1—Black-light transmitter.

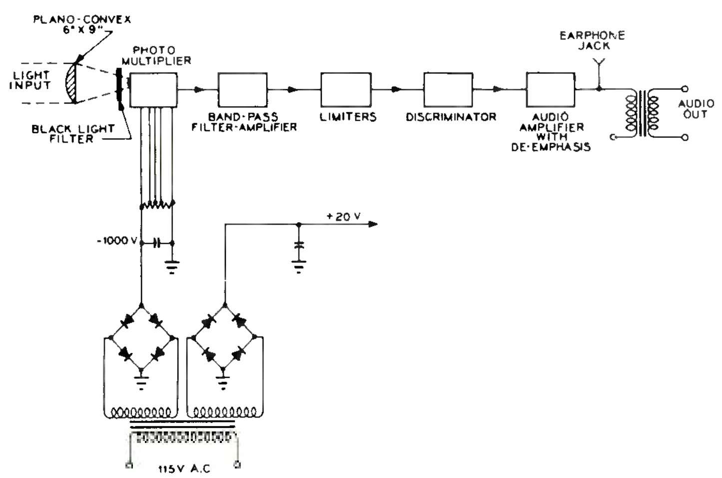


Fig. 2—Black-light receiver.

Fig. 3—At left is the black-light receiver and (right) is the hand-held black-light transmitter.

SYSTEM OPERATION

The black-light receiver employs a simple, highly directive optical system together with an ultraviolet filter. Even with this optical selectivity it does not take a very large source of light to override the relatively puny power which can be generated in a wearable transmitter—unless the desired transmission is given some characteristic coding which is radically different from anything likely to be encountered on the interfering light sources. In general, the interferences are modulated by harmonics of the 50- or 60-cps power line frequency. The intensity of modulation is usually strongest at the lower harmonics and drops off rapidly at frequencies above a few hundred cycles. At frequencies such as 50 kc, the light modulation components are almost negligible. Thus, in the present development, a 65-kc/s signal is used to amplitude-modulate the transmitted ultraviolet signal above and below a fixed light intensity. In radio parlance, this amounts to using a 65-kc/s carrier; this, in turn, is frequency-modulated ±15 kc/s by signals from the microphone circuit. Without utilizing some such distinctive modulation characteristic, it would be difficult to transmit and receive interference-free sound over more than a few feet in the presence of extremely strong 60-c/s modulated light sources.

In the receiver for the FM signal, output from a photo pickup device is routed through a bandpass filter, limiters, and discriminator in accordance with ordinary FM receiver practice. Thus, if the photo pickup were absolutely linear, the tuned circuits would pass only the desired frequencies and the system would completely reject all of the low-frequency components from the vastly stronger interfering light sources. Unfortunately, this is not the case in the present developmental equipment, since the photomultiplier pickup device introduces some degree of nonlinearity. Consequently, when the undesired ultraviolet light components are thousands of times stronger than the desired transmissions. cross-modulation products are created which impair or ruin the desired reception. As will be pointed out later. the goal of radical improvement in our overall system hinges on improved linearity of the photo pickup device ahead of the first tuned circuit.

TRANSMITTER DESIGN

The present black-light sound transmitter is illustrated in Figs. 1 and 3. The microphone works through a gain control into an audio amplifier. The amplifier employs negative feedback and high-frequency preemphasis. Frequency response is essentially flat from 30 c/s through 800 c/s and is accentuated 10 dB at 5 kc/s. The 1,000-c/s gain is 60 dB. Output from the audio amplifier is applied to variable reactance elements to modulate the frequency of a 65-c/s oscillator from 80 kc/s down to 50 kc/s. Next in the circuit is an isolation amplifier which drives the output stage. Voltage from the final power transistor is stepped up by about a 4-to-1 ratio-tuned torroid transformer and applied to a black-light glow tube which has a DC return to chassis ground. Transistor supply voltage is applied in series with the AC driving voltage from the tuned circuit. The black-light lamp itself is the well known type employing mercury vapor. Such a bulb, when operated at 60 c/s, ordinarily requires starting by way of heaters located in each end. This method of starting would be impractical in our application because of time and power requirements but it has been found that by connecting a small wire between the two end caps (one of which is grounded) starting occurs instantaneously. This results from the capacity of the grounded wire through the glass bulb. The lamp itself is rated at four watts power and our transmitter provides approximately half power operation. The built-in supply is a 30-volt Mallory mercury battery which delivers 150 mA continuously for 20 hours.

RECEIVER DESIGN

The receiver is illustrated in Figs. 2 and 3. The lens is a 6-inch-diameter, 9-inch-focal-length plano-convex of very ordinary glass. Greater response at ultraviolet wavelengths would be achieved if a higher-quality lens of special glass or quartz were used, but this would merely increase all signal levels correspondingly with little or no overall improvement because of cross-modulation in the photomultiplier. Interposed in the optical path in front of the photo cathode is a black-light filter which passes the frequencies around 3,500 angstroms. The photomultiplier is an RCA 1P28 also having peak sensitivity at the same wavelength. The tube incorporates a nine-stage electron multiplier which provides for more than the required amplification. Actually, for best results, only five or six stages of multiplication are used ahead of the first tuned circuit.

Reasonably good bandpass characteristics are achieved in the receiver through the use of three single-tuned staggered circuits and a double-tuned circuit. The discriminator is an ordinary Foster-Seely incorporating high-*L* low-*C* tightly coupled circuits for attaining the required bandwidth.

High frequency de-emphasis and audio amplification follow the discriminator. Headphone monitoring is provided and output is by way of an isolation transformer at a little below zero level. Discriminator centering may be metered and adjusted over narrow limits. The meter generally is used as a signal level indicator in order to facilitate panning and tilting when required in following movement. Thus, it is not necessary to hear an audio signal-to-noise deterioration before realizing that re-directing is desirable. The optical beam width is only about 2° to the 6-dB-down points. but good reception can generally be achieved over a much wider angle, even though the signal may be a 20 dB or more under that which would be received in the optimum direction.

The receiver is powered from the 115-volt AC line and draws only about 10 watts. A single transformer supplies high negative voltage for the photomultiplier as well as positive voltage for the transistors. All transistors are silicon in both receiver and transmitter and are type 2N706A's with the exception of the transmitter power output, a 2N1484.

MECHANICAL ASSEMBLY

The transmitter is shown photographically in Fig. 3. The microphone and lamp-support are both plug-in; also, the glow lamp is plugged into the support. The strap is normally employed for over-the-shoulder carrying. Fig. 3 also pictures the receiver. The front protrusion. which is 6 inches in diameter and 6 inches long is merely a lens hood to reduce the likelihood of interference from extremely strong ultraviolet sources located off the optical axis.

OPERATIONAL EXPERIENCE

With the present equipment, reasonably high quality speech was transmitted 0.8 mile from the Empire State Building to the RCA Building after dark. Under the test conditions, the upper portion of the Empire State Building had just been cleaned and served to reflect a tremendous amount of light from the high-powered lighting system associated with the building. On a test during the afternoon hours. it was not possible to get signals through because of the much stronger ultraviolet energy from the sun, which swamped the photomultiplier.

The utility of the present equipment is mainly at distances to 500 feet or so. Results over these short ranges have not been adversely affected by lighting conditions. Furthermore, there has always been such an excess of the desired signal at the receiver that neither smoke nor haze have caused any audible deterioration. In all but extremely short ranges, however, line of sight is required. Actually, the need for line of sight could be minimized and possibly eliminated in the future, if the receiver useful sensitivity could be increased by a decade or two. This would place it in the same class with the radio microphone in most applications, and it would actually have certain advantages, as summarized later.

POTENTIAL IMPROVEMENTS

The only basic reasons for the present useful sensitivity limit are the cross-modulation which is introduced ahead of the first tuned circuit and possibly the photocell signal-to-noise ratio under certain conditions of operation. There is a good likelihood that these can be circumvented in the near future. For example, tests have been conducted with a solid-state photo-pickup device which is linear *within 5% over a range of seven decades.* A drawback of the particular device tested was its low ultraviolet sensitivity. Output from it was so far under that from a photomultiplier that it was difficult to build up the signal to limiter level without overall amplifier feedback. It appears that these deficiencies can be solved in the future and that useful receiver sensitivity will no longer be at the mercy of nonlinearities ahead of the tuned circuits. Then, the light transmission system should work on either direct or reflected light over distances, making it a strong competitor to the radio microphone. Furthermore, experience with the present equipment indicates the following advantages: 1) *No FCC licensing requirement.* 2) *No radio transmitter or ignition type of interference.* 3) *As many transmitters as desired on a single modulating frequency with selection by receiver panning and tilting.* 4) *No standing wave problems from wave interference.*

Fig. 1—MM-1200 frequency diversity repeater.

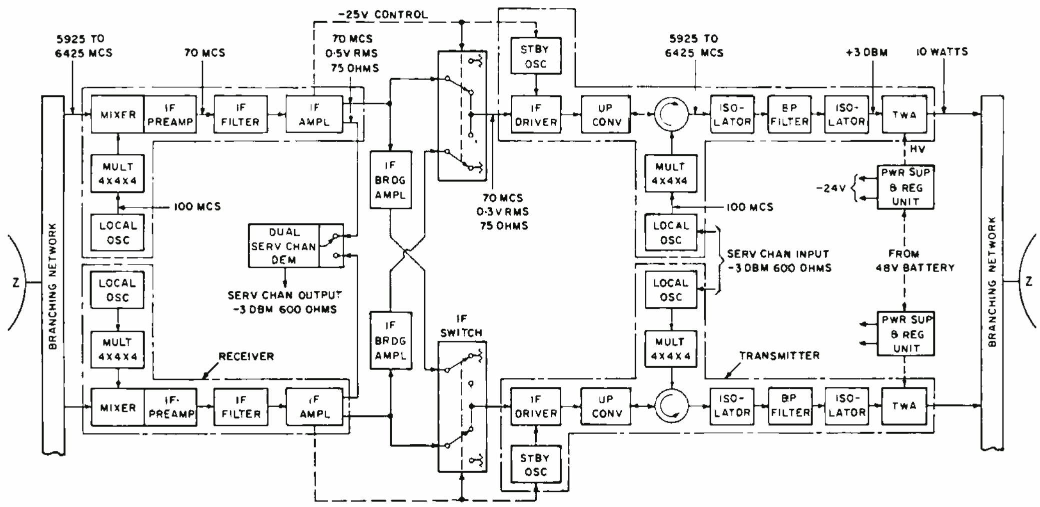
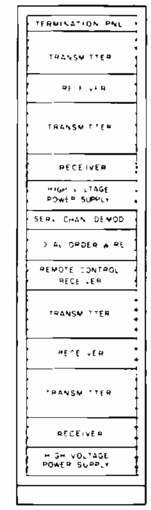


Fig. 2—MM-1200 repeater rack.



MM-1200 HIGH-CAPACITY MICROWAVE RELAY

RCA entered the high capacity microwave communication field by initiating the MM-600 development program in 1957. Between 1959 and 1963 this equipment was a leader in its field, and was used in two transcontinental systems as well as many others totaling over 450 stations. Now, emphasis by communication companies is turning to solid-state equipment to increase reliability, lower initial station costs, and reduce maintenance and operating costs. Another demand is to increase channel capacity to produce extra operating revenue for essentially the same initial cost and maintenance expense. To meet these demands of higher capacity and solid-state design and to maintain RCA's leadership in this field, a development program for a high-capacity solid-state relay equipment, the MM-1200, was undertaken in 1963 by RCA Victor Co., Ltd., Montreal. The equipment is designed to operate in the 5.9-to-6.4-Gc/s band with a 1,200-channel capacity.

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THE primary goal in the MM-1200 development program is to provide a 1,200-channel solid-state microwave equipment capable of meeting CCIR (International Radio Consultative Committee) performance requirements. A further goal is that the equipment can be readily modified with minimum cost to provide CCIR performance for 1,800-channel capacity. The system will, of course, carry one video channel with excellent quality for either monochrome or color TV.

The most important parameter in a long haul telephony system is the mean value in any hour (MVH) of the total system noise-power in any 3.1-kc/s voice channel with psophometric weighting. The CCIR requirement for this noise is that it does not exceed 3 pW/km when the system is loaded with flat noise at standard loading level.

The permissible noise allowances with 1,200-channel loading for the various thermal and intermodulation noise contributions are detailed in Table I. These are the aims for one of the nine 278-km sections of the CCIR hypothetical 2,500-km system, each section consisting of six 29-mile hops. The CCIR requirement for this section is 835 pW' maximum, leaving a margin of 1.4 dB.

SOLID STATE VERSUS TWT OUTPUT

One of the major decisions was to choose between employing a travelling wave tube in the transmitter or designing for all-solid-state components. Considerable initial development was done on a solid state design producing 5 watts at 6,000 Mc/s and using a tunnel diode amplifier at the receiver front end. However, because of the unavailability on a commercial basis of high-power, high-frequency varactors and transistors, a TWT has been selected to provide an earlier on the market date. A TWT with an average life of approximately 2 to 3 years in the MM-600 equipment indicates that this decision will not appreciably lower the system reliability.

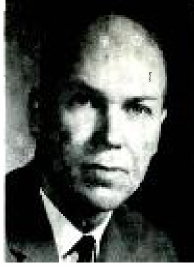
REPEATER EQUIPMENT

A block diagram of an MM-1200 diversity through-repeater is shown in Fig. 1. It does not differ in any major respect from standard heterodyne microwave repeaters.

However, with the switch from vacuum tubes to solid-state devices, with the single exception of the TWT, the detailed design of the equipment differs greatly from previous designs, e.g. MM-600. The advantages of solid-state equipment are numerous:

1) Greatly increased equipment reliabil-

Final manuscript received March 2, 1965



H. Haug

L. A. Martin

D. F. Russell

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H. HAUG received the Higher National Diploma with honors in Electrical Engineering from Brighton Technical College, England in 1950, and Diploma in Electronics from University College, Southampton England, in 1951. After working for the Norwegian Telegraph Authority, Scandinavian Airlines System and the Ericcson Telephone Co. of Brazil, he came to Canada in early 1955, where he worked for another year with the Bell Telephone Company. In 1956, he joined the Canadian Radio Mfg. Corp. to do work on microwave communication systems. He joined RCA Victor Company, Ltd. in 1958 where he has been engaged in microwave communications equipment design and development, such as the MM-600, the "Relay" communication's satellite and currently, the MM-1200, equipment.

L. A. MARTIN graduated with honors in Electrical Engineering from the University of Toronto in 1955. He then joined Shell Oil Co. and worked at various sites in North America doing electrical distribution design, piping, automatic control design and various other operations. Mr. Martin joined RCA Victor Company, Ltd. in 1958 as an engineer in the Communications Systems Group. He joined the Equipment Design Group in 1962 where he is now the leader responsible for the high capacity MM-1200 equipment.

D. F. RUSSELL graduated with honors in Electrical Engineering from McGill University in 1955. He joined RCA Victor Company, Ltd. upon graduation and spent two years on the development program of the doppler radar for the Mid-Canada Line. In 1957 he was associated with the newly formed development team for the MM-600-2 microwave relay equipment, later in a leader capacity. In 1962, he bacame supervisor of the Microwave Communications Equipment Design Group responsible for various low and high capacity microwave radio relay development projects including MM-600, MM-1200, MM-24 and MM-60. He is a member of the Corporation of Professional Engineers of Quebec and the IEEE.

V. N. SAWANT graduated from the Coventry Technical College in Coventry, England in 1954. He worked at the General Electric Co. Ltd. of England in the Equipment design group for microwave radio relay links. In 1960, he joined the RCA Victor Company, Ltd. as a design engineer in the technical products engineering group. He has been directly associated with the development of microwave radio relay equipment produced at RCA Victor. Presently he is an engineering leader responsible for design and development of various equipments for satellite communication ground stations.

ity with a similar reduction in maintenance cost.

2) Power consumption reduced by a factor of about 8 compared with tube equipment and a consequent reduction in cost and size of power supply plant.

3) Equipment size greatly reduced with a consequent reduction in cost and size of buildings required, as well as facilitating equipment transportation, installation, and maintenance.

The total power consumption of a complete two-way, frequency diversity MM-1200 repeater is less than 800 watts. All of the equipment is accommodated in a single 19-inch rack (Fig. 2).

Receiver

The mixer in the receiver (Fig. 3a) is of the balanced type, employing two mixer crystals in a 3-dB short-slot hybrid structure. The match at the signal port is 1.2 or better, and conversion loss with appropriate crystals is about 6 dB.

The IF preamplifier consists of seven amplifier stages. The first pair of stages are designed for the best practical receiver noise figure, 9.5 dB including the mixer loss. All stages have been designed for best gain flatness and low group delay distortion over the 70 ± 20 Mc/s band.

An IF bandpass filter determines the effective IF bandwidth of the receiver. It is made up of two multi-section filters, one low-pass and one high-pass connected in tandem. The extremely large attenuation above and below the passband provides a high degree of protection from spurious signal interference. Group delay of the filter is compensated for to the extent that it is less than 1 ns over the 58-to-82-Mc/s range.

The IF amplifier module provides most of the IF gain of the receiver. Like the IF preamplifier, the bandwidth is very wide, with extremely small group delay over the 70 ± 12 Mc/s range. It requires a minimum of initial adjustments because of the wideband characteristics of its circuits. The AGC is accomplished by single diode pads between isolating amplifier stages, thus preventing deterioration. This results in only slight deterioration of the gain-frequency characteristic throughout the AGC range of the unit.

A squelch circuit, operated by the AGC DC-amplifier, provides control signals for the transmitters and alarms in case the received signal drops below the receiver threshold level. The squelch level can be set within a wide range to suit individual systems requirements.

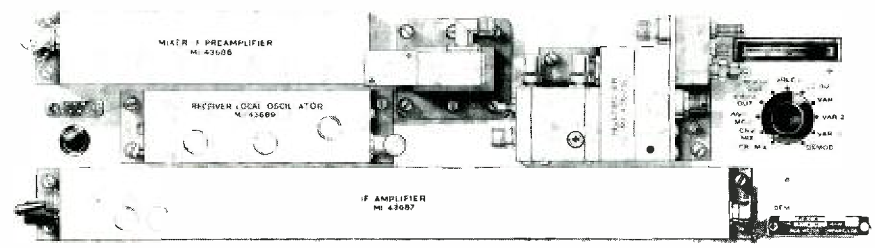


Fig. 3a—The MM-1200 receiver unit.

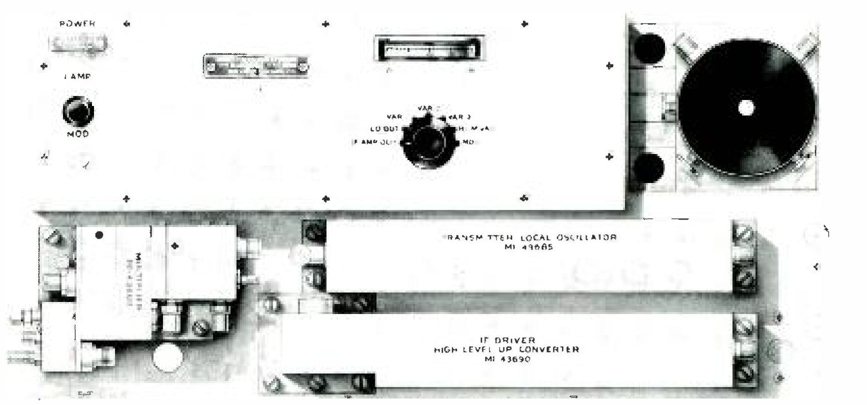


Fig. 3b—The MM-1200 transmitter unit.

The receiver local oscillator unit is similar to the transmitter local oscillator, except that insert facilities are not required.

The receiver frequency multiplier chain is mechanically identical to the transmitter local-oscillator multiplier chain, but the required efficiency is considerably lower, about 1% overall.

Transmitter

The IF and squelch outputs of the receivers are connected to the IF switches on the transmitter panels (Fig. 3b). The squelch outputs control the *on-off* condition of the respective IF switches. In this way, protection at IF is obtained in every repeater.

The IF switch consists of diodes suitably biased by the control circuitry. Its switching transfer speed, limited by the drive circuitry, is a fraction of a micro-

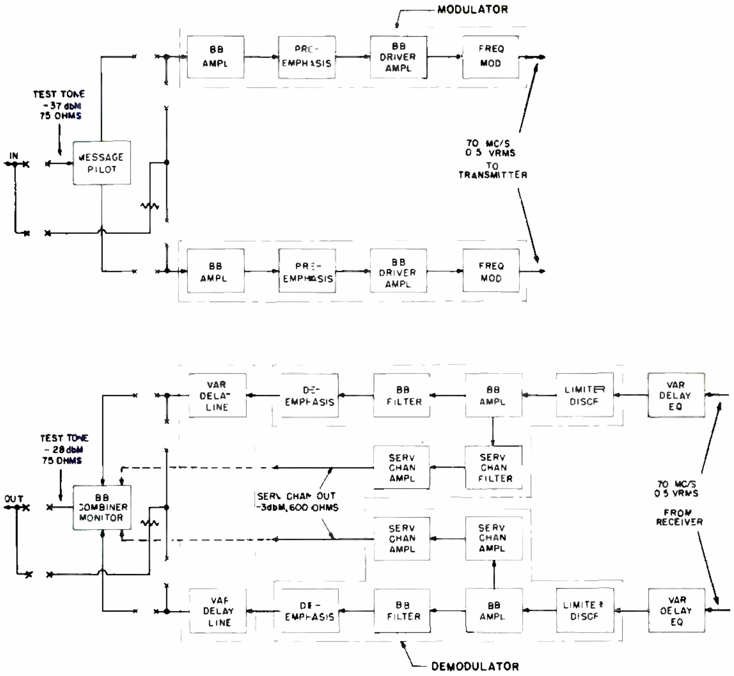


Fig. 4—MM-1200 frequency diversity terminal.

second. Isolation is better than 90 dB forward loss less than 1 dB, and return loss of all ports of the unit greater than 26 dB.

The IF bridging amplifier is a broadband, three-stage, unity-voltage-gain, high-input-impedance amplifier, providing another 75-ohm IF output for the second transmitter.

The IF driver amplifier is a six-stage wideband IF amplifier. It incorporates two stages of IF limiters providing better than 30-dB AM compression. This high degree of AM suppression keeps IM noise due to AM-PM conversion in subsequent equipment to a minimum. The amplifier's output stage, delivering about 3.5 volts-RMS, drives the varactor switch in the upconverter.

The upconverter is essentially an RF switch in a single RF port waveguide structure. This structure contains a wideband RF transformer to provide optimum match to the varactor for maximum conversion efficiency, as well as a coaxial IF port for driving the varactor switch.

In practice, with losses in the switching varactor and other imperfections, the RF-to-sideband loss is about 6 dB. To separate the incident and reflected RF power, a three-port circulator is used. A waveguide filter transmits the desired sideband to the TWT and reflects the residual carrier and all other sideband frequencies, which are then absorbed by an isolator.

Standby IF oscillators are built into each IF driver-up-converter unit. Both receiver squelch signals are applied to logic circuitry which turn on both standby IF oscillators in case of double failure of received signals to both diversity receivers. In this way, IF drive to the upconverter is preserved by the oscillator IF carrier, and the remainder of the link kept fully operational from the point of complete failure of received signals. As soon as either or both receivers pick up a signal of adequate strength, both IF standby oscillators are turned off by the squelch circuits, and transmission through the repeater is restored.

The local oscillator module consists of a crystal controlled Butler oscillator, operating at about 100 Mc/s. It is followed by a power-amplifier stage, which delivers 2 watts to the output. To keep random phase modulation noise to a minimum, a narrowband resonator is incorporated at the output of the unit, providing large attenuation for noise sidebands removed by 0.5 Mc/s or more from the carrier frequency. The high-frequency stability required, ±5 ppm maximum over the temperature range of −20°C to + 65°C, has been achieved without any temperature control in the unit by using a special type of crystal plus careful design of the oscillator circuit.

Insert facilities are provided in two channels:

1) *Service* (0.3 to 20 kc/s) carries order wire, alarms and other signals. It is accomplished by direct FM of the crystal oscillator by a varactor circuit.
2) *Traffic Insert* (60 to 300 kc/s) inserts traffic channels at repeater stations. A total of 60 voice channels can be accommodated this way. It is achieved by indirect FM of the local-oscillator carrier by a phase modulator.

The local-oscillator frequency multiplier chain multiplies the 100 Mc/s of the transistor oscillator to desired local-oscillator frequency in the 6-Gc/s band. It consists of three varactor quadrupler stages in tandem. The first stage employs lumped constant circuitry, while the two last stages are a combination of coaxial and circular cavity structures. The overall efficiency of the unit is about 5% using common grades of varactors. With the high conversion efficiency of the up-converter, ample RF drive power is available for the TWT.

The TWT provides a minimum of 10 watts of output power over the 6-Gc/s band. Apart from providing adequate noise figure, gain, temperature stability, etc., considerable effort was expended to obtain a tube with a low AM-PM conversion factor to minimize IM noise generation in the tube. It is conduction cooled, and like other parts of the equipment it does not require any blowers.

To prevent any appreciable second harmonic power transmitted by the TWT from being reflected by the RF branching network filters back into the TWT output port, thus causing interference, a harmonic absorber is inserted between the TWT output and the RF branching network.

Service Channel Demodulator

The service channel demodulator provides communication facilities to the repeaters, e.g. orderwire, remote control, and other signals in the 0.3-to-20-kc/s band. A single unit is used for each direction operating on either of two receivers as shown in Fig. 1. The receiver squelch circuits operate the IF switch at the input of the unit, ensuring continuity of communication as long as either receiver provides an IF signal.

Power Supply

The power supply operates on 48-volt DC supplies. It consists of two main parts, the DC regulator, followed by the DC-DC converter.

The DC regulator is of the switching, variable-pulse-width type, operating at 10 kc/s. Because of the switching mode of operation, efficiency is very high, better than 90% under normal load conditions. It will keep its output at 38 volts with any source voltage between 42 and 60 volts, and any load current between 0.2 and 10 amps.

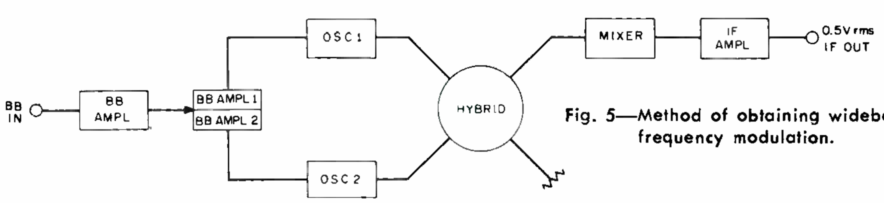


Fig. 5—Method of obtaining wideband frequency modulation.

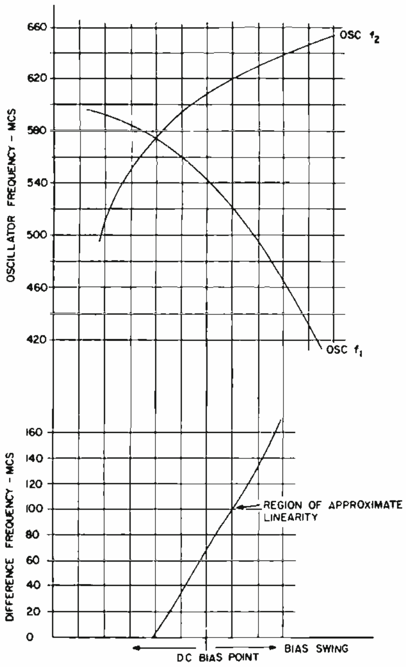


Fig. 6—Difference frequency of two UHF oscillators with opposing modulation (curvature is exaggerated for illustration).

The regulator is followed by the DC-DC converter, operating at about 660 c/s. It converts the 38 volt-DC to the DC voltage and power levels required for the various transistor and TWT circuits in the MM-1200 equipment. It also delivers a 660-c/s square wave for auxiliary TWT supplies. Its efficiency under normal full load is better than 90%. Hence, the overall efficiency of the power supply unit is 85% under normal load conditions, when it is supplying about 300 watts total to two transmitters, two receivers, one service channel demodulator, and one order wire unit.

Since a single power unit supplies all the power for one channel of a diversity repeater, it has been designed for maximum reliability by using components of ample ratings as well as by reducing power dissipation to a minimum in all critical components.

TERMINAL EQUIPMENT

Fig. 4 is a block diagram of the MM-1200 terminal equipment. To feed the multiplex information into the radio equipment at the transmit end, a message pilot insert unit, a baseband amplifier, a pre-emphasis unit, and 70-Mc/s modulator are used. At the receiver end, a 70-Mc/s demodulator, a variable delay line, a baseband combiner and monitor unit, and a level regulator are used to extract the multiplex information.

Modulator

The FM modulator output frequency is 70 Mc/s. To achieve this the outputs of two oscillators (545-Mc/s & 615 Mc/s) differing in frequency by 70 Mc/s are beat together. The arrangement is shown in Fig. 5.

A low-noise, high-frequency transistor in a common base configuration is used as an oscillator. The varactor is placed across the oscillator tuned circuit and the oscillator frequency is changed by varying the bias across the varactor. To achieve modulation a baseband amplifier provides the variable varactor bias at the modulating frequency.

The frequency shifts occurring in two oscillators due to change in varactor bias are in opposition to each other. If oscillator *1* changes frequency by −1 Mc/s, then oscillator *2* changes by +1 Mc/s, so actual frequency deviation at the difference frequency is equal to twice the deviation of each of the oscillators.

When a varactor is used for changing the oscillator frequency, there is a nonlinear relationship between frequency and the varactor bias as shown in Fig. 6. But Fig. 6 shows how the resultant at the difference frequency produces a characteristic which has a linear-frequency-to-DC-bias relationship.

The oscillator frequency is substantially higher than the beat frequency of 70 Mc/s. Thus, 10% frequency deviation at 70 Mc/s is less than 0.7% deviation at any of the two oscillator frequencies.

Better linearity over a wider frequency deviation range can be achieved with this method of modulation. Fig. 7 shows the linearity achieved in practice. The wideband amplifier that follows the mixer provides enough gain so that the output is 0.5 volt-RMS nominally in 75-ohm load.

Demodulator

The demodulator consists of limiters, a discriminator, and a baseband amplifier. Diode limiters are used for compression of amplitude modulation that may be present on the 70-Mc/s carrier frequency. The AM compression of 18 dB per limiter stage is achieved by using two fast-switching diodes in a shunt configuration. The diode limiters are driven by transistor amplifiers, and followed by a discriminator. The discriminator is a transistor stage having at its output a two-pole multi-resonance network which provides discriminator action between the series and parallel impedance points. In essence, it converts frequency modulation into amplitude modulation. This is followed by a diode detector.

This circuit was selected mainly for its simplicity. It needs only a single-ended drive, and only one detector is used. It is insensitive to the harmonics of the RF drive.

Using this discriminator, a linearity of better than 1% over a 30-Mc/s band has been obtained. The discriminator is followed by a baseband amplifier providing −28-dBm test tone level at the output terminal.

Modem Performance

The overall linearity of modulator and demodulator working together (Fig. 7) is better than 2% over ±15 Mc/s with respect to 70 Mc/s. For 1,200-channel loading with test tone deviation of 200 kc/s, a noise-power ratio of better than 55 dB is achieved.

Baseband Diversity Unit

This unit will allow either combining or switching options. The baseband combiner will be of the linear adder type. A comprehensive monitoring arrangement will be used to monitor the level of the continuity pilot and the system noise on a visual basis with extensive automatic alarm facilities.

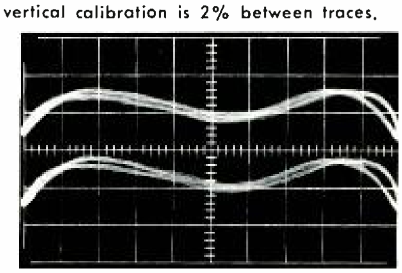
RF TRANSMISSION SYSTEM

Branching Network

The branching network uses ferrite circulators and bandpass filter-isolator combinations in a fashion somewhat similar to that employed by the MM-600-6 equipment. Two major differences have been introduced in the MM-1200 for saving both cost and space. Whereas the MM-600-6 network used four-port circulators exclusively and a separate branching circulator for each transmitter or receiver, the MM-1200 design uses a four-port circulator for the antenna multiplexing circulator only and a three-port branching circulator plus a duplexer tee for the first pair of receivers or transmitters with only a duplexer tee for the final pair of receivers or transmitters on each antenna (Fig. 8). Some tightening of specifications is required on the three-port circulators to permit this simplified arrangement, but presently developed circulators now make this feasible at a fraction the cost of the four-port units.

The bandpass filters (four ranges to cover the band of 5,925 to 6,425 Mc/s) duplexer tees, terminations, and miscel-

Fig. 7—Modulator-demodulator linearity measurement; horizontal sweep is ±15 Mc/s and vertical calibration is 2% between traces.



laneous waveguide components are being designed and will be manufactured by RCA Victor Co., Ltd. A computer program for the complete mechanical dimensioning of any waveguide filter to various specifications in any band has being created.

Four-port multiplexing circulators, three-port branching circulators, and ferrite isolators may be purchased, but their possible manufacture by RCA Victor Co., Ltd. is under consideration.

Waveguide

Extruded aluminum waveguide (50S-T5 magnesium silicon wrought alloy), with internal dimensions of WR159 and a circular external configuration will be used between the branching network and antenna.

This waveguide-hanger arrangement was developed by RCA Victor Co., Ltd. and successfully used on the Montreal-to-Vancouver MM-600-6 system. The novel design provides equal moments of inertia for all axes passing through the center of the cross section, high tensile strength of about 35,000 lbf/in^2 yield strength and minimum wind resistance. Voltage reflections per flanged joint are 0.2 to 0.25% and attenuation per 100 feet is 1.65 dB.

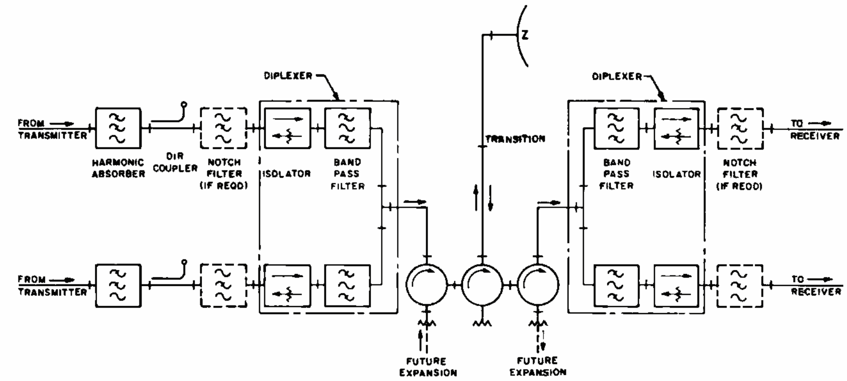
The waveguide is connected to the antenna by either an *E*- or *H*-plane rigid 90° bend and suspended from a single 12-bolt clamp at the pivot point of the antenna mount. Horizontal movement of the waveguide running down the tower is controlled by restrainers which permit rotation of the waveguide in both the horizontal and vertical planes as well as vertical movement.

Antenna

A 10-foot-diameter deep paraboloid antenna with 43.5-dB gain and greater than 65-dB front-to-back ratio is employed. This antenna was developed for the Montreal-to-Vancouver MM-600-6 system.

To obtain the high front-to-back ratio while at the same time maintaining high aperture efficiency, a Cassegrain feed system is employed, consisting of a horn near the vertex of the paraboloid and a hyperboloid subreflector whose focus corresponds with the focus of the dish.[1]

The feed system is protected from the elements by a 1-inch-thick polyurethane foam radome. The antenna mount pivots horizontally and vertically about the base of the mount.



NOTE—NOTCH FILTER REQUIRED FOR CHAN 18 & CHAN 22

Fig. 8—MM-1200 branching network showing combination of diplexers and circulators.

MAINTENANCE AND METERING PHILOSOPHY

The greatly increased reliability as well as the compact size of solid-state microwave equipment call for new approaches to the problems of maintenance and metering. In nearly all cases, field repairs in a system will be achieved by replacing modules or whole units rather than individual components. As a consequence, the metering of the equipment is designed mainly to check and monitor the functions of the various modules rather than components. To facilitate metering, each unit is provided with its own meter, rotary switch, and associated circuitry.

With the high reliability of the equipment, routine maintenance will not be required more than once or twice a year. For the same reason, field repairs due to equipment failures will be rather rare. Hence, a rather small crew of field technicians will be able to take care of all maintenance of a fairly large number of microwave stations. These technicians will require a thorough knowledge of the functions of the various units and modules as well as how to check these in a system, but will not require much detailed knowledge of module designs.

The service center will be equipped to perform detailed checking, fault locating, and repair of practically all electronic equipment involved in the system. Again, a small, but in this case a more highly trained staff of technicians will be able to handle all normal repairs for a large microwave system.

A typical maintenance procedure in case of an outage at a microwave repeater is as follows:

The nature of the failure and its approximate location in the equipment is determined as far as alarm and other remote monitoring circuits permit. A field maintenance technician then travels to the site. He takes a module or a set of them, or even complete units that will cover all fault possibilities as indicated by analysis of the various remote alarm indications. After a check at the site reveals the faulty module, it is replaced and returned by the technician to the microwave system service center for repair and storage as a spare unit.

CONTINUING PROGRAM

By some modification to the terminal equipment and upgrading of the RF transmission system, 1,800-channel capacity could be achieved. Also, the improvement of 1,200 channel performance to better than 2 pW/km for special international system circuits is being investigated. Use of square or circular waveguide would be a necessary part of this improvement.

Many prospective customers requiring this type of equipment cannot operate in the 5.9-to-6.4-Gc/s common-carrier frequency band. Thus, consideration is being given to several adjacent bands in the 6.4-to-8.2-Gc/s frequency range.

Many of the video, IF, and RF modules and techniques being developed for this program are now being employed in wideband receivers and exciters for satellite communications such as NASA's Rosman (N.C.) ATS Station and Canada's Satellite Communications Ground Station.

ACKNOWLEDGEMENTS

The authors, who are responsible for the radio equipment design, acknowledge the contributions of all those in the Equipment Design Groups, under the supervision of V. E. Isaac, who have participated in this development program.

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TABLE I — Noise Allowance, 6-Hop Section

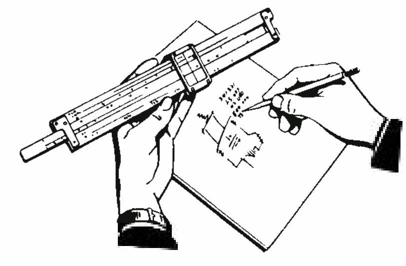
278-km length, 1,200-channel loading, CCIR Emphasis, 200-foot towers, worst channel.

	Noise Per Hop*, pW	Total Section Noise*, pW
Thermal noise MVH	30	180
TWT + LO	15	90
Modem, thermal	—	10
Group delay distortion / AM-PM Conversion	—	190
Feeder distortion	7	42
Antenna coupling	8	48
Baseband distortion	—	47
		607 picowatts

* Data are psophometrically weighted

Engineering and Research NOTES

BRIEF TECHNICAL PAPERS OF CURRENT INTEREST



RF Switching Matrix Achieves 140-dB Isolation

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Final manuscript received May 11, 1965

In recent years, frequency synthesizers using electronic tuning have come into common usage in RF generators for test apparatus and in radio sets. These synthesizers are of various types: *mixer, divide-by-N*, etc. Some mixer types have a requirement that any one of a given number of frequencies can be applied as an input to any one of a number of mixers. This implies the use of an RF switching matrix. A typical synthesizer may use ten frequencies; up to five of these frequencies must be routed by means of the switching matrix to five mixers, the particular combination being governed by the final output frequency desired. This requires a 10 x 5 switching matrix containing 50 crosspoint switches, the individual switches being solid-state devices controlled by a single control line per switch.

The switching matrix described here was designed for an SSB transceiver. The specifications called for an *on*-to-*off* signal ratio of greater than 140 dB for a switch and interfrequency crosstalk greater than 140 dB down. *This would be at least two orders of magnitude improvement over any known switching matrix.* Operating frequency range was 4 to 5 Mc/s.

Measuring Technique: For measuring the *on*-to-*off* attenuation ratio of the switch, a generator with at least a 140-dB range, plus a receiver with a meter on the IF output that will respond to a level of about 0.5μV at 5 Mc/s were required. A signal of approximately 0.5μV was applied to the switch while on, and a reference was established on the meter. The switch was then turned off, and the generator output increased until the reference was reached. Crosstalk was measured by turning on two adjacent switches in the matrix and applying a large signal to one of the switches. The output of this switch and the input of the adjacent switch were terminated with a resistor equal to the impedance of the system. The receiver was connected to the output of the adjacent switch.

The first circuit considered consisted of three diodes and a resistor (Fig. 1). Ideally, the generator and receiver supply DC paths for the bias current. With a positive voltage applied to R_1, *CR1* and *CR2* conduct, and the switch is *on*.

The resistance of a forward biased diode in the proximity of the "knee" is given by $R = KT/eI = 0.025/I$, where K = Boltzmann's constant, T = absolute temperature, °K, e = charge on an electron, and I = diode current in amps. If V_2 and R_1 are chosen so that at least 5 mA flows through *CR1* and *CR2*, the resistance is approximately 5 ohms per diode. If the input signal is small (less than 0.1 volt-RMS) the insertion loss of the switch is $20 \log ([R_g + R_S]/[R_L]) = 20 \log ([50+5+5]/[50]) = 1.6$ dB, where R_g = generator output impedance, R_S = diode conduction resistance, and R_L = receiver input impedance.

For large input signals, the bias current is appreciably reduced by the positive swings of the input signal, and the insertion loss increases. With a negative voltage applied to R_1 (Fig. 1) *CR3* conducts, *CR1* and *CR2* are reverse biased by approximately 0.7 volt, and the switch is *off*. The attenuation presented to the 5-Mc/s signal was calculated to be about 124 dB. If the circuit is constructed with adequate electrostatic shielding, the calculations can be verified by measurements.

Final Circuit: To get the desired increase in isolation, additional series diodes were added (Fig. 2). Calculations showed that this circuit should give at least 130 dB attenuation; however, a difficulty was encountered when performing the measurement.

Conduction through *CR3* causes a reverse bias of about 0.7 volt to be established for the series diode. If the peak negative signal swing exceeds 0.7 volt, the series diodes on the input side (*CR4* and *CR1*) become forward biased, and leakage through the *off* switch becomes excessive. With the measuring scheme described above, it is not possible to set a reference with a small signal, then turn the switch *off* and increase the signal above 120 dB, without "breaking through" the bias.

Further modification of the original circuit (Fig. 3) gave a much greater reverse bias. In this circuit, since there is no path to ground through R_1 with *off* bias applied, *CR4* and *CR1* are back-biased by the full amount of V_1. This provides a double benefit: Not only are the input diodes prevented from being forward-biased by large input signals, but also the effective capacitance of *CR4, CR1*, and *CR2* is reduced. (*CR3* is moved to the junction of *CR2* and *CR5* to provide the transmission zero to ground.) The R_2 and *CR6* are added to supply *off* bias current to *CR3*.

Using the specification for a typical low capacitance diode and letting $V_1 = -6$ volts, the capacitance of *CR4, CR1*, and *CR2* is 1.0 pF. The capacitance of *CR5* is 1.5 pF. The attenuation of this circuit is calculated to be about 140 dB.

With the design of the switch circuit completed, the problem remained to provide a package which would accommodate 50 switches, 15 RF connectors, and 50 control lines. In addition, each control line required an RFI filter. Fig. 4 shows the completed matrix.

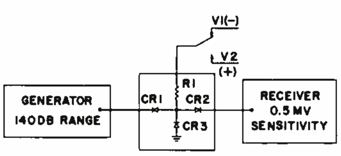


Fig. 1—Three-diode switch.

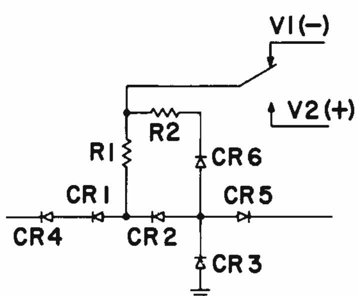


Fig. 3—Final switch circuit.

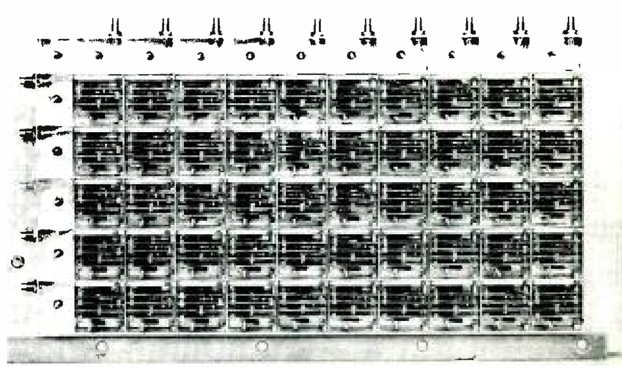


Fig. 4—Completed switching assembly, 10x5 matrix with 50 crosspoint switches.

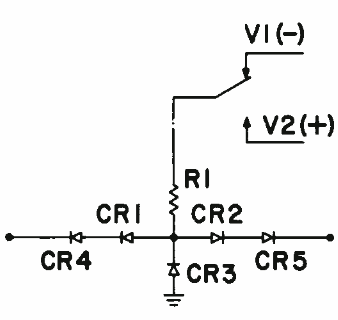
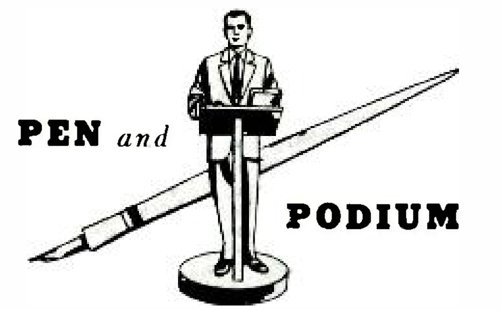


Fig. 2—Improved performance version.



A SUBJECT-AUTHOR INDEX TO RECENT RCA PAPERS

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Teutsch, W. B. solid-state materials physical-chemical structure
Teutsch, W. B. atomic theory; phenomena
Tietjen, J. J. lasers
Todo, M. solid-state materials electronic properties
Torre E. Della solid-state materials electronic properties
Tosima, S. solid-state materials magnetic properties
Tosima, S. atomic theory; phenomena
Tosima, S. electromagnetic theory; phenomena
Vieland, L. J. superconductivity; cryoelectrics
Volkman, J. E. acoustic theory; phenomena
Warfield, G. solid-state materials electronic properties
Waxman, A. solid-state materials electronic properties
Weimer, P. K. solid-state materials electronic properties
Weimer, P. K. displays
Weinstein, H. solid-state materials magnetic properties
Whitaker, H. H. instrumentation; lab equipment
White, J. G. solid-state materials physical-chemical structure
White, J. G. solid-state materials physical-chemical structure
Williams, R. solid-state materials electronic properties
Wittke, J. P. solid-state materials physical-chemical structure
Woodward, J. G. recording components; materials
Wysocki, J. J. energy conversion; sources

Patents Granted

TO RCA ENGINEERS

As Reported By RCA Domestic Patents, Princeton

RCA LABORATORIES

A Fast High Current Driver Using Tunnel Diodes—J. C. Miller (Labs, Pr.) *U.S. Pat. 3,171,038* (Assigned to U.S. Gov't.) Feb. 23, 1965

Control Apparatus for Induction Heating System—A. G. Fischer (Labs, Pr.) *U.S. Pat. 3,177,336*, Apr. 6, 1965

Means for Modifying the Waveform of a Pulse as it Passes Through Controlled Delay Line—A. J. Simon, H. Weinstein (Labs, Pr.) *U.S. Pat. 3,177,433*, Apr. 6, 1965

Dynamic Limiter for Stereophonic Broadcast Receiver—F. R. Holt (Labs, Pr.) *U.S. Pat. 3,178,514*, Apr. 13, 1965

Method of Making Semiconductor Devices—R. E. Quinn, J. H. McCusker (Labs, Pr.) *U.S. Pat. 3,179,542*, Apr. 20, 1965

Television Brightness and Contrast Control Circuit—R. W. Ahrons, L. L. Burns, Jr. (Labs, Pr.) *U.S. Pat. 3,179,743*, Apr. 20, 1965

Pickup Tube Target Structure and Method of Manufacturing the Same—S. A. Ochs (Labs, Pr.) *U.S. Pat. 3,179,834*, Apr. 20, 1965

Electrical Circuits Employing Semiconductor Devices—W. H. Cherry (Labs, Pr.) *U.S. Pat. 3,181,080*, Apr. 27, 1965

Memory Systems—M. W. Green (Labs, Pr.) *U.S. Pat. 3,181,126*, Apr. 27, 1965

Apparatus for Measuring Differential Temperature—L. E. Barton (Labs, Pr.) *U.S. Pat. 3,181,364*, May 4, 1965

Magnetic Memory—G. R. Briggs, R. Shahbender (Labs, Pr.) *U.S. Pat. 3,183,579*, May 18, 1965

Insulation—L. L. Burns, Jr. (Labs, Pr.) *U.S. Pat. 3,184,329*, May 18, 1965

Switching Systems—W. F. Kosonocky, L. S. Onyshkevych (Labs, Pr.) *U.S. Pat. 3,184,601*, May 18, 1965

Generator Circuits Employing Storage Diodes—G. B. Herzog (Labs, Pr.) *U.S. Pat. 3,184,605*, May 18, 1965

Electrostatic Printing—E. C. Giaimo, Jr. (Labs, Pr.) *U.S. Pat. Re 25,779*, May 18, 1965

Loudspeakers—H. F. Olson, J. Preston (Labs, Pr.) *U.S. Pat. 3,185,767*, May 25, 1965

Tunnel Diode Shift Register with Automatic Reset—J. J. Amodei, J. R. Burns (Labs, Pr.) *U.S. Pat. 3,185,864*, May 25, 1965

Magneto-Resistance Nonreciprocal Signal Amplifier—K. K. N. Chang (Labs, Pr.) *U.S. Pat. 3,185,937*, May 25, 1965

Multi-Junction Negative Resistance Semiconducting Devices—U. Rappaport, E. Pasierb, Jr. (Labs, Pr.) *U.S. Pat. 3,187,193*, June 1, 1965

Transistor with Emitter at Bottom of Groove Extending Crosswise the Base—H. Nelson, J. Bernath (Labs, Pr.) *U.S. Pat. 3,187,241*, June 1, 1965

Impedance Inverter Coupled Negative Resistance Amplifiers—T. G. Marshall, Jr. (Labs, Pr.) *U.S. Pat. 3,187,266*, June 1, 1965

Monostable Multivibrator Having Emitter Follower Feedback Controlled by a Timing Network—D. P. Dorsey (Labs, Pr.) *U.S. Pat. 3,188,489*, June 8, 1965

Beam Penetration Color Cathode Ray Tube—H. B. Law, J. J. Thomas, J. Gross (Labs, Pr.) *U.S. Pat. 3,188,507*, June 8, 1965

Beam Penetration Color Cathode Ray Tube—J. J. Thomas (Labs, Pr.) *U.S. Pat. 3,188,508*, June 8, 1965

DEFENSE ELECTRONIC PRODUCTS

Electromagnetic Constant Velocity Actuator—L. H. Fulton, T. D. Tilton (DEP-MSR, Moorestown) *U.S. Pat. 3,176,170*, Mar. 30, 1965

Fluid Applicator Apparatus—R. C. Hansen (DEP-AppRes, Camden) *U.S. Pat. 3,176,653*, Apr. 6, 1965

Apparatus for Providing Fluid Bearings—M. T. Durlofsky (DEP-CSD, Camden) *U.S. Pat. 3,177,493*, Apr. 6, 1965

Decoders for Transponders or the Like—D. P. Clock, J. H. Pratt (DEP, L.A.) *U.S. Pat. 3,178,705*, Apr. 13, 1965

Transponder Decoder—D. P. Clock (DEP, L.A.) *U.S. Pat. 3,178,706*, Apr. 13, 1965

Memory—R. L. Pryor, T. R. Mayhew (DEP, AppRes, Camden) *U.S. Pat. 3,181,131*, Apr. 27, 1965

Memory—H. Amemiya (DEP, AppRes, Camden) *U.S. Pat. 3,181,132*, Apr. 27, 1965

Data Storage Apparatus—M. L. Levene (DEP, AppRes, Camden) *U.S. Pat. 3,181,166*, Apr. 27, 1965

Projection Apparatus—M. T. Durlofsky (DEP-CSD, Camden) *U.S. Pat. 3,181,418*, May 4, 1965

Circuit Supporting Apparatus—M. E. Ecker (DEP-AppRes, Camden) *U.S. Pat. 3,184,650*, May 18, 1965

Computer Circuit—H. E. Haynes (DEP-AppRes, Camden) *U.S. Pat. 3,184,732*, May 18, 1965

Analog to Digital Converters—L. H. Werner, C. H. Sie (DEP-CSD, Camden) *U.S. Pat. 3,185,977*, May 25, 1965

Speed Control System Using Parallel Control Loops—F. E. Shashoua, R. C. Wilcox (DEP-AppRes, Camden) *U.S. Pat. 3,187,092*, June 1, 1965

AC Modulator Protective Device—R. J. Carl, C. B. Parkinson, Jr. (DEP-L.A.), *U.S. Pat. 3,093,771* (Assigned to U.S. Gov't.) June 11, 1963

ELECTRONIC COMPONENTS AND DEVICES

Depositing Epitaxial Layer of Silicon from a Vapor Mixture of SiH_4 and H_2—A. Mayer, J. Lesky (ECD, Som.) *U.S. Pat. 3,177,100*, Apr. 6, 1965

Color-Kinescopes of the Line-Screen Sensing Variety—T. A. Saulnier (ECD, Lanc.) *U.S. Pat. 3,177,389*, Apr. 6, 1965

Grid Support Structure—J. J. Free (ECD, Lanc.) *U.S. Pat. 3,177,392*, Apr. 6, 1965

Method of Photocell Manufacture by Simultaneously Sintering the Photosensitive Material and Sealing the Cell—H. W. Kuzminski (ECD, Lanc.) *U.S. Pat. 3,177,576*, Apr. 13, 1965

Thermionic Energy Converters—F. G. Block (ECD, Lanc.) *U.S. Pat. 3,179,822*, Apr. 20, 1965

Pickup Tube Having a Cesiated Photocathode and a Substantially Leckage-Free Target, and Method of Making the Same—P. W. Kaseman (ECD, Lanc.) *U.S. Pat. 3,179,835*, Apr. 20, 1965

Electron Tube Mount Including Two Electrodes Supported on a Common Insulating Header—C. T. Johnson (ECD, Lanc.) *U.S. Pat. 3,179,837*, Apr. 20, 1965

Modular Structures and Methods of Making Them—E. Luedicke, H. Reinig (ECD, Som.) *U.S. Pat. 3,179,854*, Apr. 20, 1965

Method of Brazing a Plurality of Leads to Apertures in a Ceramic Wafer—W. W. Allen, E. R. Larson (ECD, Hr.) *U.S. Pat. 3,180,020*, Apr. 27, 1965

Method of Supplying a Plurality of Wires—C. W. Lindsley, E. R. Larson (ECD, Hr.) *U.S. Pat. 3,180,189*, Apr. 27, 1965

Tray and Tray Unload Mechanism—P. Maurer (ECD, Hr.) *U.S. Pat. 3,180,505*, Apr. 27, 1965

Shielding of Electron Gun from Vaporizing Getter by Decomposable Foil Over Electrode Aperture—R. E. Benway (ECD, Marion) *U.S. Pat. 3,183,391*, May 11, 1965

Apparatus for Assembling an Electron Tube Cage—P. R. Smith (ECD, Hr.) *U.S. Pat. 3,183,577*, May 18, 1965

Method of and Apparatus for Cutting and Deburring Tubes—A. H. Zittell (ECD, Hr.) *U.S. Pat. 3,183,702*, May 18, 1965

Electron Tube Parts Handling Apparatus—A. Fischer, Jr. (ECD, Hr.) *U.S. Pat. 3,183,703*, May 18, 1965

Package—R. Kuhlman (ECD, Hr.) *U.S. Pat. 3,184,054*, May 18, 1965

Packages for Electronic and Other Components—T. W. Kisor (ECD, Som.) *U.S. Pat. 3,184,056*, May 18, 1965

Method of Manufacturing Electron Discharge Devices—J. F. Miller (ECD, Hr.) *U.S. Pat. 3,184,278*, May 18, 1965

Apparatus for Sealing and Exhausting—G. A. Shaffer, Jr. (ECD, Hr.) *U.S. Pat. 3,184,279*, May 18, 1965

Cathode Ray Tube Having Deflection Enhancement Means—J. Evans, Jr. (ECD, Lanc.) *U.S. Pat. 3,185,879*, May 25, 1965

Electron Tube and Socket—O. H. Schade, Sr. (ECD, Hr.) *U.S. Pat. 3,185,954*, May 25, 1965

Container for an Electrical Component—M. J. Grimes (ECD, Som.) *U.S. Pat. 3,187,083*, June 1, 1965

Electron Dynamic Beam Convergence Apparatus for Color Receiver—R. R. E'del (ECD, Lanc.) *U.S. Pat. 3,187,218*, June 1, 1965

Pentode Oscillator Deflection Circuit with Feed Back—W. M. Austin, J. A. Dean (ECD, Hr.) *U.S. Pat. 3,187,219*, June 1, 1965

Method for Making Semiconductor Junction Devices—R. A. Straight, W. P. Alina (ECD, Som.) *U.S. Pat. 3,188,251*, June 8, 1965

Compensation for Vertical Component of Earth's Magnetic Field by Color Triad Displacement—J. L. Hudson (ECD, Lanc.) *U.S. Pat. 3,187,650*, June 8, 1965

ELECTRONIC DATA PROCESSING

Dynamic Focus Circuit—F. E. Brooks (EDP, Cherry Hill) *U.S. Pat. 3,177,396*, Apr. 6, 1965

Vertical Deflection Circuit for Television Receivers—F. E. Brooks (EDP, Cherry Hill) *U.S. Pat. 3,179,842*, Apr. 20, 1965

Print Registration Control Means in High Speed Printers—D. M. Fisher, J. E. Linnell (EDP, Camden) *U.S. Pat. 3,183,830*, May 18, 1965

HOME INSTRUMENTS DIVISION

Multifunction Axially Movable Knob Control for Channel Selection, Fine Tuning and Volume Control—N. G. Kelln (H.I., Indpls.) *U.S. Pat. 3,177,432*, Apr. 6, 1965

Method for Preparing Ferrite Core—J. O. Simpkiss, Jr. (H.I., Indpls.) *U.S. Pat. 3,178,369*, Apr. 13, 1965

Magnet Holder—J. M. Ammerman (H.I., Indpls.) *U.S. Pat. 3,179,857*, Apr. 20, 1965

Tuning System for Television Receivers—R. D. Brand (H.I., Indpls.) *U.S. Pat. 3,179,907*, Apr. 20, 1965

BROADCAST AND COMMUNICATIONS DIV.

Information Storage Apparatus Utilizing a Record of Internally Reflective, Light Conducting Material—H. W. Robinson (BCD, Camden) *U.S. Pat. 3,177,476*, Apr. 6, 1965

Bistable Device—H. Ur (BCD, Camden) *U.S. Pat. 3,185,860*, May 25, 1965

Meetings

DATES and DEADLINES

PROFESSIONAL MEETINGS AND CALLS FOR PAPERS

July 6-8, 1965: SAN DIEGO SYMP. FOR BIOMEDICAL ENG., IEEE, San Diego Sect., U.S. Naval Hosp., et al.; San Diego, Calif. *Prog. Info.:* Dean L. Franklin, Scripps Clinic & Res. Found., LaJolla, Calif.

July 12-25, 1965: ANN. IEEE CONF. ON NUCLEAR & SPACE RADIATION EFFECTS, IEEE, G-NS, et al.; Univ. of Mich., Ann Arbor, Mich. *Prog. Info.:* S. Clay Rodgers, Sandia Corp., Sandia Base, Albuquerque, N. M.

Aug. 23-27, 1965: 6TH INTL. CONF. ON MEDICAL ELEC. & BIOLOGICAL ENG., IEEE, IFMEBE; Tokyo, Japan. *Prog. Info.:* Dr. L. E. Flory, RCA Labs., Princeton, N. J.

Aug. 24-27, 1965: WESCON (WESTERN ELECTRONICS SHOW & CONVENTION), IEEE, WEMA; Cow Palace, San Francisco, Calif. *Prog. Info.:* IEEE, Don Larson, L. A. Office, 3600 Wilshire Blvd., Los Angeles, Calif.

Aug. 24-26, 1965: 20TH NATL. CONF. OF THE ASSOCIATION FOR COMPUTING MACHINERY; Sheraton-Cleveland Hotel, Cleveland, Ohio. *Prog. Info.:* G. J. Moshos, Tech. Prog. Chairman, ACM 65, PO Box 4741, Cleveland, Ohio.

Aug. 10-Sept. 1, 1965: ANTENNAS & PROPAGATION INTL. SYMP., IEEE, G-AP; Sheraton Pk. Hotel, Wash., D. C. *Prog. Info.:* Dr. R. J. Adams, Search Radar Branch, Naval Res. Labs., Wash., D. C.

Sept. 8-10, 1965: 13TH ANN. INDUS. ELEC. & CONTROL INST. CONF., IEEE, G-IECI, Phila. Section; Sheraton Hotel, Phila., Pa. *Prog. Info.:* Prof. P. L. Balise, Dept. of Mech. Eng., Univ. of Wash., Seattle 5, Wash

Sept. 13-17, 1965: 6TH NATL. ELECTRICAL INSULATION CONF., IEEE, G-EI-NEMA, et al.; N. Y. Hilton at Rockefeller Ctr., N. Y., N. Y. *Prof. Info.:* H. W. Marquardt, NEMA, 155 E. 44th St., N. Y., N. Y.

Sept. 13-14, 1965: 13TH ANN. JOINT ENG. MTG. CONF., IEEE-ASME, et al.; N. Y. Hilton Hotel, New York, N. Y. *Prog. Info.:* T. Marble, Toronto Star Ltd., 80 King St., Toronto, Ont., Canada.

Sept. 19-22, 1965: NATL. POWER CONF., IEEE-ASME; Sheraton-Ten Eyck Hotel, Albany, N. Y. *Prog. Info.:* IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Sept. 22-24, 1965: INTL. CONVENTION ON MILITARY ELECTRONICS (MIL-E-CON 9), IEEE, G-MIL; Wash. Hilton Hotel, Wash., D. C. *Prog. Info.:* L. H. King, Jansky & Bailey Div., Atlantic Res. Corp., Alexandria, Va.

Sept. 23-25, 1965: 15TH IEEE BROADCAST SYMP., IEEE-G-B; Willard Hotel, Wash., D. C. *Prog. Info.:* S. Bergen, 103 Fairchester Dr., Fairfax, Va.

Sept. 24-25, 1965: 13TH ANN. COMMUNICATIONS CONF., IEEE, Cedar Rapids Sect.; Cedar Rapids, Iowa. *Prog. Info.:* IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Sept. 28-29, 1965: 7TH BIENNIAL ELECTRIC HEATING CONF., IEEE, G-IGA; Hotel Carter, Cleveland, Ohio. *Prog. Info.:* A. F. Leatherman, Bettelle Memorial Inst., 505 King Ave., Columbus 1, Ohio.

Oct. 4-6, 1965: 1965 CANADIAN ELECTRONICS CONF., IEEE, Region 7; Automotive Bldg., Toronto, Ont., Canada. *Prog. Info.:* Canadian Elec. Conf., 1819 Yonge St., Toronto 7, Ont., Canada.

Oct. 5-7, 1965: 2ND INDUSTRIAL & COM. POWER SYSTEMS CONF., IEEE, G-IGA; Statler-Hilton Hotel, Buffalo, N. Y. *Prog. Info.:* J. A. Hart, Allison Div. of Gen. Motors, Box 894, Indianapolis 6, Ind.

Oct. 6-8, 1965: 6TH ANN. SYMP. ON SWITCHING CIRCUIT THEORY & LOGICAL DESIGN, IEEE, G-C Univ. of Mich.; Univ. of Mich., Ann Arbor, Mich. *Prog. Info.:* Dr. J. Hartmanis, G.E. Res. Lab., Schenectady 1, N. Y.

Oct. 11-13, 1965: 1965 IEEE NATCOM (COMMUNICATIONS SYMP.), IEEE, G-Com-Tech Mohawk Valley Section; Utica, N. Y. *Prog. Info.:* IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Oct. 12-14, 1965: 1965 PROTECTIVE RELAYING CONF., IEEE, Twin Cities Sect. & Univ. of Minn.; Univ. of Minn., Minneapolis, Minn. *Prog. Info.:* IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Oct. 18-20, 1965: 12TH NUCLEAR SCIENCE SYMP., IEEE, G-NS; San Francisco Hilton Hotel, San Fran., Calif. *Prog. Info.:* J. M. Harrer, Argonne Natl. Labs., Argonne, Ill.

Oct. 18-20, 1965: JT. MATERIALS HANDLING CONF., IEEE, G-IGA-ASME; Pittsburgh Hilton, Pittsburgh, Pa. *Prog. Info.:* IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Oct. 20-22, 1965: ALLERTON CONF. ON CIRCUIT & SYSTEM THEORY, IEEE, G-CT, Univ. of Ill.; Conf. Center, Univ. of Ill., Monticello, Ill. *Prog. Info.:* Prof. ME Van Valkenburg, Univ. of Ill., Monticello, Ill.

Oct. 20-22, 1965: ELECTRON DEVICES MEETING, IEEE-G-ED; Sheraton Park Hotel, Wash., D. C. *Prog. Info.:* IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Oct. 25-27, 1965: NATL. ELECTRONICS CONF., IEEE, et al.; McCormick Place, Chicago, Ill. *Prog. Info.:* R. G. Brown, EE Dept., Iowa State Univ., Ames, Iowa.

Oct. 25-27, 1965: 4TH SYMP. ON DISCRETE ADAPTIVE PROCESSES, IEEE, G-IT, G-AC; McCormick Place, Chicago, Ill. *Prog. Info.:* J. H. Eaton, IBM Res. Labs., Monterey & Cottle Rds., San Jose, Calif.

Oct. 25-27, 1965: 2ND SYMP. ON CONSUMER ELEC., IEEE, G-BTR, G-ED; McCormick Place, Chicago, Ill. *Prog. Info.:* IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Oct. 27-29, 1965: EAST COAST CONF. ON AEROSPACE & NAVIG. ELEC. (ECCANE), IEEE, G-ANE, Baltimore Section; Holiday Inn, Baltimore, Md. *Prog. Info.:* R. Allen, Westinghouse Elec. Corp., Molecular Elec. Div., Baltimore, Md.

Nov. 1-3, 1965: 4TH INDUSTRY WIDE CONF. ON INDUSTRIAL STATIC POWER CONVERSION, IEEE; Benjamin Franklin Hotel, Phila., Pa. *Prog. Info.:* W. Porter, Aluminum Corp. of America, 1501 Alcoa Bldg., Pittsburgh 19, Pa.

Nov. 2-4, 1965: IEEE INTL. SPACE ELECTRONICS SYMP., IEEE, G-SET; Fontainbleu Hotel, Miami Beach, Fla. *Prog. Info.:* Thos. Broskie, NASA, Cape Kennedy Complex, Cocoa Beach, Fla.

Jan. 25-27, 1966: 12TH ANN. SYMP. ON RELIABILITY, IEEE, G-R, ASQC, et al.; Sheraton Palace Hotel, San Francisco, Calif. *Prog. Info.:* A. R. Park, General Precision, Inc., 1370 Encinitas Rd., San Marcos, Calif.

Calls for Papers

Sept. 22-24, 1965: 1965 IEEE CONF. ON MILITARY ELECTRONICS (MIL-E-CON 9), IEEE; Washington Hilton Hotel, Wash., D. C. **Deadline:** Abstracts, 4/15/65; Manuscripts, **7/15/65.** *TO:* Leon H. King, Chairman. Tech. Program Committee, Atlantic Res. Corp., Shirley Highway at Edsall Rd., Alexandria, Va.

Oct. 11-13, 1965: 11TH NATCOM SYMP., IEEE Mohawk Valley Section; Utica, N. Y. **Deadline:** Abstracts, 6/7/65; Manuscripts, **9/1/65.** *TO:* G. E. Brunette, Tech. Prog. Chairman, Communications Div., (EMCT), Rome Air Development Center, Griffiss AFB, N. Y.

Oct. 18-20, 1965: 12TH NUCLEAR SCIENCE SYMP., IEEE, G-NS; San Francisco Hilton Hotel, San Fran., Calif. **Deadline:** Abstracts, **7/1/65.** *TO:* J. M. Harrer, 12th NSS Program Chairman, Argonne Natl. Lab., Argonne, Ill.

Oct. 31-Nov. 5, 1965: 98TH TECH. CONF. & EQUIPMENT EXHIBIT, Soc. of Motion Picture & Television Engrs. (SMPTE); Queen Elizabeth Hotel, Montreal, Quebec, Can. **Deadline:** Abstracts, **8/16/65.** *TO:* R. S. Rekert, Natl. Film Board of Canada, c/o SMPTE, 9 E. 41st St., N. Y. 17, N. Y.

Nov. 3-5, 1965: NEREM (NORTHEAST ELE. RES. & ENG. MTG.), IEEE, Region 1; Sheridan Boston & Civic Auditorium, Boston, Mass. **Deadline:** Abstracts, approx. **8/1/65.** *FOR INFO.:* NEREM, IEEE Boston Office, 313 Washington St., Newton 58, Mass.

Nov. 10-12, 1965: 18TH ANN. CONF. ON ENG. IN MEDICINE & BIOLOGY, IEEE, G-BME-ISA; Univ. of Penna. & Sheraton Hotel, Phila., Pa. **Deadline:** Abstracts, approx. **8/1/65.** *FOR INFO.:* Dr. H. Schwan, Moore School of EE, Univ. of Penna., Phila., Pa.

Nov. 15-18, 1965: 11TH ANN. CONF. ON MAGNETISM & MAG., IEEE-AIP; Hilton Hotel, San Francisco, Calif. **Deadline:** Abstracts, approx. **8/1/65.** *FOR INFO.:* IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Nov. 30-Dec. 1-2, 1965: FALL JOINT COMPUTER CONF., IEEE, AFIPS, ACM; Convention Center, Las Vegas, Nevada. **Deadline:** Abstracts, approx. **7/1/65.** *FOR INFO.:* IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Jan. 31-Feb. 3, 1966: SYMP. ON INFORMATION THEORY, IEEE, G-IT; UCLA, Los Angeles, Calif. **For Deadline Info.:** A. V. Balakrishnan, 7609 W. 91 Place, Los Angeles, Calif.

Feb. 9-11, 1966: INTL. SOLID STATE CIRCUITS CONF., IEEE, G-CT, Univ. of Pa.; Phila., Pa. **Deadline:** Abstracts, approx. **11/1/65.** *FOR INFO.:* IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Mar. 2-4, 1966: SCINTILLATION & SEMICONDUCTOR COUNTER SYMP., IEEE, G-NS; Shoreham Hotel, Wash., D. C. **For Deadline Info.:** W. A. Higinbotham, Brookhaven Natl. Labs., Upton, L. I., N. Y.

Mar. 21-24, 1966: IEEE INTL. CONVENTION, IEEE, All Groups TAB; Coliseum & N. Y. Hilton, N. Y., N. Y. **Deadline:** Abstracts, approx. **10/19/65.** *FOR INFO.:* IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Apr. 19-21, 1966: 1966 INTL. NONLINEAR MAGNETICS CONF. (INTERMAG), IEEE, G-Mag VDE; Stuttgart, Germany. **For Deadline Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Apr. 20-22, 1966: SOUTHWESTERN IEEE CONF. & ELEC. SHOW (SWIEEECO), IEEE, Region 5; Dallas Memorial Auditorium, Dallas, Texas. **Deadline:** Abstracts, approx. **10/1/65.** *FOR INFO.:* IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Apr. 26-28, 1966: SPRING JOINT COMPUTER CONF., IEEE, AFIPS, ACM; Boston Civic Ctr., Boston, Mass. **For Deadline Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

May 3-4, 1966: PACKAGING INDUSTRY CONF., IEEE; Hartford, Conn. **For Deadline Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

May 4-6, 1966: 1966 ELECTRONIC COMPONENTS CONF., IEEE, G-CP, EIA; Marriott Motor, Washington, D. C. **Deadline:** Abstracts, approx. **10/9/65.** *FOR INFO.:* IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

May 10-12, 1966: NATL. TELEMETERING CONF., IEEE (Host) AIAA-ISA; Prudential Center, Boston, Mass. **Deadline:** Abstracts, approx. **10/1/65.** *FOR INFO.:* Dr. A. J. Kelley, NASA-ERC, 575 Tech. Square, Cambridge, Mass.

May 16-18, 1966: NAECON (NATL. AEROSPACE ELEC. CONF.), IEEE, G-ANE-AIAA, Dayton Section; Dayton, Ohio. **Deadline:** Abstracts, approx. **12/15/65.** *FOR INFO.:* IEEE Dayton Office, 1414 E. 3rd St., Dayton 3, Ohio.

May 16-18, 1966: 1966 NATL. SYMP. ON MICROWAVE THEORY & TECH., IEEE, G-MTT; Palo Alto, Calif. **Deadline:** Abstracts, approx. **11/15/65.** *FOR INFO.:* IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

June 15-17, 1966: 2ND IEEE INTL. COMMUNICATIONS CONF., IEEE, G-ComTech., et al.; Sheraton Hotel, Phila., Pa. **For Deadline Info.:** A. E. Joel, Jr., Bell Telephone Labs., Holmdel, N. J.

June 20-22, 1966: SAN DIEGO SYMP. FOR BIOMEDICAL ENG., IEEE, U.S. Naval Hosp.; San Diego, Calif. **For Deadline Info.:** Dean L. Franklin, Scripps Clinic & Res. Found., LaJolla, Calif.

June 20-25, 1966: 3RD IFAC CONGRESS, IEEE, IFAC; London, England; **For Deadline Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

June 21-23, 1966: CONF. ON PRECISION ELECTROMAGNETIC MEASUREMENTS, IEEE, G-IM NBS; NBS Standards Lab., Boulder, Colorado. **For Deadline Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

July 18-21, 1966: 1966 AEROSPACE CONF. (AEROSPACE & ELECTRONIC SYSTEMS CONF.), IEEE; Olympia Hotel, Seattle, Washington. **Deadline:** Abstracts, **9/15/65.** *TO:* T. J. Martin, 3811 E. Howell St., Seattle, Washington. *FOR FURTHER INFO.:* D. B. Dobson, RCA, Burlington, Mass.

Be sure deadlines are met—consult your Technical Publications Administrator or your Editorial Representative for the lead time necessary to obtain RCA approvals (and government approvals, if applicable). Remember, abstracts and manuscripts must be so approved BEFORE sending them to the meeting committee.

Engineering NEWS *and* HIGHLIGHTS

1964 ECD ENGINEERING ACHIEVEMENT AWARDS

RCA Electronic Components and Devices has awarded its *1964 Engineering Achievement Awards* to 20 engineers, as follows:

W. B. Hall, Special Electronic Components Division, Harrison, N.J.—*for ingenuity in the development of a method to compensate radioisotope temperature changes.*

G. Cohen and **H. Criscito,** Special Electronic Components Division, Somerville, N.J.—*for valuable contributions to integrated circuits for the RCA Spectra-70 computer.*

D. D. Mawhinney, Industrial Tube and Semiconductor Division, Harrison, N.J.—*for important advances in the design of receiver circuitry for aircraft radar.*

D. R. Carley, Industial Tube and Semiconductor Division, Somerville, N.J.—*for outstanding contributions to the design and development of high-frequency power transistors.*

D. E. Burke and **H. Weisberg,** Industrial Tube and Semiconductor Division, Harrison, N.J.—*for numerous contributions to the design and application of thyristors.*

R. A. Donnelly, Commercial Receiving Tube and Semiconductor Division, Findlay, Ohio—*for significant contributions to power transistor manufacturing techniques.*

A. E. Hoggett, Commercial Receiving Tube and Semiconductor Division, Cincinnati, Ohio—*for numerous engineering contributions to receiving tube manufacturing.*

R. A. Bonnette and **E. F. Kashork,** Commercial Receiving Tube and Semiconductor Division, Harrison, N.J.—*for noteworthy contributions to the design and application of vacuum tubes in television receivers.*

A. M. Trax and **P. W. Wolverton,** Television Picture Tube Division, Marion, Ind. —*for excellence in development and implementation of an implosion protection system for television picture tubes.*

J. M. Fanale, S. A. Harper, J. S. Martin, M. R. Royce, J. P. Stanavage and **S. S. Trond,** Television Picture Tube Division, Lancaster, Pa. — *for outstanding achievement in the development and implementation of improved color phosphors.*

E. F. Cave, Technical Programs, Somerville, N.J.—*for important contributions to the development of solid state device technology.*

DR. GEORGE H. BROWN ELECTED EXECUTIVE VICE PRESIDENT

Election of **Dr. George H. Brown** as Executive Vice President, Research and Engineering, has been announced by RCA Chairman **David Sarnoff** and President **Elmer W. Engstrom.** Dr. Brown has overall responsibility for RCA's research and engineering programs, reporting directly to Dr. Engstrom.

Dr. Brown joined RCA in 1933, after receiving his PhD from the University of Wisconsin. He was first a research engineer with the RCA Manufacturing Company in Camden, N.J., where he developed the turnstile antenna used for transmitting television, FM radio, and facsimile signals. In 1942, he transferred to the then-new RCA Laboratories in Princeton, N.J. During World War II he was responsible for important advances in antenna development for military systems, and for the development of RF heating techniques.

From 1948 to 1957, Dr. Brown played a leading part in the direction of RCA's research and development of color and UHF television. In 1957, he was appointed Chief Engineer of RCA Commercial Electronic Products Division at Camden, and 6 months later was named Chief Engineer, RCA Industrial Electronic Products. In 1959, he was appointed Vice President, Engineering, for the entire Corporation, and in 1961, he became Vice President, Research and Engineering for RCA. He is on the Board of Directors of RCA Communications, Inc.

A prolific inventor, Dr. Brown holds numerous patents in electronics and communications. He is a member of the National Academy of Engineering, and is a *Fellow* of the IEEE and the American Association for the Advancement of Science, as well as a Member of Sigma Xi and the Franklin Institute.

M. P. ROSENTHAL WINS STWP AWARD FOR ARTICLE

Murray P. Rosenthal, DEP-CSD Systems Lab., New York City, has been named to receive the *1964-65 Technical Publications Award* of the Society of Technical Writers and Publishers for his article on "How to Write a Technical Book and Get It Published," which appeared in the *IEEE Transactions on Engineering Writing and Speech* (EWS 7-2, Sept. 1964). The article also appeared in the RCA ENGINEER (Vol. 10-2, Aug.-Sept. 1964) in a shorter version. The award was the first prize in the STWP Bi-Annual Awards, in the category "magazine article published or unpublished."

Mr. Rosenthal is himself a successful author of technical books; his professional background at RCA includes both engineering, and technical writing and editing. He is RCA ENGINEER Editorial Representative for the N.Y. Systems Lab, where he is a Senior Member of the Technical Staff, and where he supervises technical publications activities.

DR. G. H. BROWN ELECTED TO ENGINEERING ACADEMY

Dr. George H. Brown, Executive Vice President, Research and Engineering, has been honored by election to membership in the recently formed National Academy of Engineering. One of nineteen distinguished engineers chosen because of their "*important contributions to engineering theory and practice or because of unusual accomplishment in the pioneering of new and developing fields of technology,*" Dr. Brown was installed as a member at the first annual meeting of the new Academy in Washington, D.C.

The National Academy of Engineering was established in 1964 under the same Congressional charter as the National Academy of Sciences, founded 102 years ago. The culmination of long-range efforts on the part of the NAS and Engineers Joint Council, the new engineering academy is affiliated with the academy of sciences. **Dr. E. W. Engstrom,** President of RCA, is one of the new academy's 25 founding members.

RESIDENT PATENT COUNSELS IN CAMDEN, HARRISON AREAS

RCA personnel in the Camden and Harrison areas can obtain ready assistance with all patent matters, problems, and questions by contracting the Resident Senior Patent Counsels assigned to their respective areas. Two members of Patent Operations have been named to provide closer and faster liaison between Patent Operations, Princeton, N.J., and the Harrison and Camden areas.

Morris A. Rabkin, Resident Senior Patent Counsel for the Camden area, is in Cherry Hill, Bldg. 204-1 (PY-5711). He services all activities in Camden, Cherry Hill, and Moorestown. **William A. Zalesak,** Resident Senior Patent Counsel for the Harrison area, is in Harrison, Bldg. 19-4 (TH-2577). He services all activities in the Harrison-Somerville complex plus ECD facilities in Lancaster, Marion, and Mountaintop.

According to **Frank S. Misterly,** Staff Vice President, Patent Operations, the two men do not replace existing Patent Operations functions, but rather supplement them by providing RCA personnel in the two areas with direct contacts for handling various patent matters, including such things as how to keep adequate records to support the dates of, and facts relating to, inventions, how to file invention disclosures, how to process patent approval matters to make sure they are no prior patents held by others on products about to be released and marketed by RCA activities, and for such other patent services as may be required of them.

FIRST U.S. COMMERCIAL MICROWAVE SYSTEM, RCA-BUILT 19 YEARS AGO, RE-EQUIPPED FOR HIGH CAPACITY

The final relay station in the first U.S. commercial microwave system, installed 19 years ago, has been re-equipped for high-capacity service. The South Jersey station was a part of the first system, linking New York, Philadelphia and Washington, over which The Western Union Telegraph Company began transmitting messages in 1946 without benefit of pole lines. The system's 36-channel microwave was the first commercial radio relay equipment built by RCA. Its design was based on RCA's World War II experience in radar and high-frequency communications.

That original RCA CW-1 and CW-2 microwave equipment has been replaced by the RCA MM-600 transmitter-receivers, which form the backbone of Western Union's new 7,500 mile transcontinental microwave network (described in RCA ENGINEER, Vol. 8-3 by Privett and Forbes). The MM-600 Union network equipment production and installation added up to the largest single microwave project ever undertaken at one time, involving 236 relay and terminal stations.

15 CHILDREN OF RCA EMPLOYEES WIN RCA NATIONAL MERIT SCHOLARSHIPS

The *1965 RCA National Merit Scholarships for Children of RCA Employees* have been awarded to 15 high school seniors on the basis of scholastic aptitude, leadership ability and good citizenship, as announced by **Dr. Douglas H. Ewing,** Staff Vice President, RCA.

The four-year college scholarships, sponsored by RCA in cooperation with the National Merit Scholarship Corporation, carry stipends up to $1,500 annually. The program, in some instances, also provides for financial aid to the colleges selected by the RCA Merit Scholars.

When the Fall Term starts this year, a total of 54 children of RCA employees will be actively enrolled in college under RCA scholarships.

The RCA Merit Scholars for 1965 are:

Patricia A. Gonyo will enroll at Florida Presbyterian College to major in anthropology. Her father, W. C. Gonyo, is with RCA Electronic Data Processing, Palm Beach Gardens, Fla., where he is an Experimental Shop Technician.

Ernest H. Gaw will enroll at Rice University, Texas. He will major in physics or mathematics. His father, **Ernest D. Gaw,** is with the RCA Service Company, Shreveport, La. where he is a Theatre Service Engineer.

Nancy R. Jefferis will enroll at Mount Holyoke College to major in nursing. Her father, **Herschel R. Jefferis,** is with the RCA Service Company, Dallas, Texas, where he is a Theatre Service Engineer.

William H. Roberts, Jr. will enroll at Yale University to major in pre-law. His father, **William H. Roberts,** is with the RCA Service Company, Florida, where he is an Associate Engineer.

David H. Dolinko will enroll at Columbia University to major in physics. His father, **Meyer Dolinko,** is an Instructor at the RCA Institutes, Inc., N.Y.

Albert C. Reisz will enroll at Massachusetts Institute of Technology to major in physics. His father, **Albert Reisz,** is with RCA Broadcast and Communications Products Division, Camden, N.J., where he is a Design and Development Engineer.

Joseph F. Donoghue will enroll at Princeton University to major in aeronautics. His father, **Joseph F. Donoghue,** is with RCA Broadcast and Communications Products Division, Camden, N.J., where he is Warehousing Manager in the Production Department.

Edward W. Petrillo will enroll at Princeton University to major in chemistry. His father, **Edward W. Petrillo** is with RCA Defense Electronics Products, Moorestown, N.J., where he is a manager, Ships Operation Management Office.

Sarah J. Graetz will enroll at Swarthmore College to major in Biochemistry. Her father **George M. Graetz,** is with RCA Electronic Components and Devices, Lancaster, Pa., where he is Administrator, Coordination and Controls, Industrial Tube and Semiconductor Division.

Richard Nowogrodzki will enroll at Harvard College to major in Mathematics. His father, **Markus Nowogrodzki,** is with RCA Electronic Components and Devices, Harrison, N.J., where he is Manager of Microwave Engineering Programs for the Industrial Tube and Semiconductor Division.

J. William Pezick will enroll at Deep Springs College, California to major in philosophy and political science. His father, **Joseph W. Pezick** is with RCA Electronic Components and Devices, Lancaster, Pa., where he is a Tool Estimator and Checker in the Industrial Tube and Semiconductor Division.

Kenneth R. Sloan will enroll at Brown University to major in aeronautical engineering. His father, **Kenneth R. Sloan,** is with RCA Electronic Components and Devices, Harrison, N.J., where he is an Equipment Designer, Microwave Support Engineering.

M. Frederick Brewer will enroll at Pomona College to major in applied physical chemistry. His father, **Morton S. Brewer,** is with the National Broadcasting Company, where he is a Transmitter Engineer with Station KNBC, Burbank Calif.

Richard M. Jacobson will enroll at Bucknell University to major in chemistry. His father, **Max M. Jacobson,** is retired from the National Broadcasting Company, where he was Supervisor of Technical Operations Production.

Dean A. Logan will enroll at Lehigh University to major in engineering. His father, **Ray P. Logan,** is with the RCA Corporate Staff in New York City, where he is Administrator of Auditing Services.

FIVE AT RCA LABS RECEIVE DOCTORAL STUDY AWARDS FOR 1965-1966

The following men have received *Doctoral Study Awards* from RCA Labs. for 1965-66:

Juan J. Amodei joined RCA as an engineer in the Commercial Electronic Products Division in March, 1957 and transferred to RCA Laboratories in December, 1959. He is presently in the Computer Research Laboratory working on high speed computer circuits. He plans to continue his doctoral studies in electrical engineering at the University of Pennsylvania.

Philip M. Heyman joined RCA Laboratories in February, 1963 as a Member of the Research Training Program. He expects to receive his MS degree in EE in May 1965 from Princeton University where he will pursue his doctoral studies. He is presently a Member of the Technical Staff in the Electronic Research Laboratory.

Henry S. Kurlansik received his bachelor's degree in Engineering Physics in 1962 and his Master of Business Administration in 1963 from Cornell University prior to joining RCA Laboratories as a Member of the Research Training Program. He is presently completing his MS degree in Physics at the University of Pennsylvania and plans to spend next year working on his Ph.D. in Electrical Engineering. He is on the Computer Research Laboratory staff.

Kenneth G. Petzinger will attend the University of Pennsylvania to pursue his doctoral studies in Electrical Engineering. He received his Bachelor of Arts degree in Physics in 1963 from Princeton University and then joined RCA Laboratories as a Member of the Research Training Program. He is presently completing his requirements for an MS in Physics from Columbia University and is a Member of the Technical Staff in the Microwave Research Laboratory.

David G. Ressler joined RCA Laboratories as a Member of the Research Training Program in 1963 after completing a Bachelor of Science degree in Chemistry in 1960 and a Bachelor of Science degree in Electrical Engineering in 1963 from Rutgers-The State University. He will receive his Master of Science degree in Electrical Engineering from the University of Pennsylvania in May and plans to pursue doctoral studies in solid state electronics. Ressler is a Member of the Technical Staff, Systems Research Laboratory.

ANDERSON WINS SLOAN FELLOWSHIP

Richard H. Anderson of the RCA Service Company, Columbus, Ohio, has been awarded an *Alfred P. Sloan Fellowship in Executive Development* at the MIT School of Industrial Management. He is one of 45 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.

Mr. Anderson, who is 39, started with RCA in 1951 as an Office Manager Trainee. He was appointed to his present position, District Manager, Consumer Products Service, in 1964. He received a BS in Business Administration from Boston University in 1951.

DR. ZWORYKIN RECEIVED BRITISH IEE "FARADAY MEDAL"

Dr. Vladimir K. Zworykin, Honorary Vice-President of RCA, has been awarded the *Faraday Medal*. The IEE Council made this, the 43rd award of the medal, to mark Dr. Zworykin's notable scientific and industrial achievements including the invention of the iconoscope, and for his important role in medical electronics.

The Faraday Medal may be awarded by the Council, not more frequently than once a year, for notable scientific or industrial achievement in electrical engineering or for conspicuous service rendered to the advancement of electrical science. The recipient need not necessarily be a member of the British IEE, and there is no restriction as regards his nationality or country of residence. This was presented to Dr. Zworykin in London on April 29, 1965.—*C. W. Sall*

INTERSERVICE DATA EXCHANGE PROGRAM

RCA has participated in the Interservice Data Exchange Program (IDEP) since its inception by the military services in 1960. The number of participating contractors is 163. By providing a medium for the effective interchange of test results, IDEP serves to greatly reduce the overlapping effort among companies working on closely related problems. While concerned primarily with component and part testing, the scope of IDEP also encompasses the testing of materials, and processes and techniques relating to aerospace equipments.

The operation of IDEP within RCA is simple. In essence, relevant test reports initiated by RCA are summarized on the appropriate IDEP summary sheet and a copy of the report and summary sheet are sent to the part supplier for his information and comments. After satisfactory coordination with the supplier, the report is sent to IDEP Headquarters to be processed. At the IDEP data distribution center, the complete report is microfilmed, and copies of the microfilm together with summary card are sent to all participating contractors and agencies.

RCA is furnished eight sets of the summary cards and associated microfilms submitted by all of the participating contractors. These, as well as all other correspondence with IDEP, are processed through **Charles Divor,** the Contractor Data Coordinator (CDC) located in DEP Central Engineering, Building 1-6 Camden. The CDC in turn distributes one copy to each of the seven DEP divisional representatives. Each representative maintains, file and necessary reproduction equipment in his area. Over 3,000 test reports were distributed to each of the divisional locations during 1964.

Indexes are compiled periodically by IDEP, and copies are available in each divisional area. RCA personnel may examine any IDEP report and, if necessary, secure a copy by contacting their nearest divisional location.

This program is most effective when there are a large group of reports constantly coming into the program. Cooperation is solicited of all RCA engineers by Mr. Divor to assure that applicable test reports on parts, materials, and related categories generated in the various divisional areas are made available to IDEP. Also, specific examples of cases in which IDEP reports have effected significant savings would be useful. Contact your divisional representative for information on submitting applicable reports to IDEP.

The following individuals are the current representatives at the various DEP locations: CSD, Camden, **T. Story,** 13-3; CSD, Tucson, Ariz., **L. Wigington,** AED, Princeton, N. J., **J. Kimmel,** 414-1; M&SR, Moorestown, N. J., **P. F. Sprowls,** 101-109; ASD, Van Nuys, Calif., **E. Wendkos,** 307-2; and ASD, Burlington, Mass., **V. P. Frolich,** 33.

Engineers in other RCA activities should contact Mr. Divor.

. . . PROMOTIONS . . .

to Engineering Leader & Manager

As reported by your Personnel Activity during the past two months. Location and new supervisor appear in parenthesis.

RCA Communications, Inc.

J. C. Hepburn: from Mgr., Station Facilities Eng. to *Mgr., Equipment & Systems Design* (Vice President and Chief Engr., Equipment & Systems Design)

Broadcast and Communications Products Division

W. Autry: from Sr. Member, Eng. Staff to *Ldr., Eng. Staff* (K. L. Neumann, Mgr., 2-Way Mobile Eng., Meadow Lands)

D. C. Pastore: from Engr., Design and Development to *Ldr., Design and Development Engr.* (B. F. Melchionni, Electronic Recording, Projectors, Magnetic Heads and Scientific Instruments Eng., Camden)

RCA Service Company

M. A. King: from Engr. to *Ldr., Systems Analysis* (C. S. Cummings, Systems Analysis, Missile Test Project)

W. G. McGuffin: from Systems Service Engr. to *Ldr., Systems Svc. Engrs.* (E. Minzenberger, Aerospace and Comms. Project)

J. P. Newey: from Engr. to *Ldr., Engrs.* J. W. Martin, Signature Support Eng., Missile Test Project)

J. E. Reeder: from Engr. to *Ldr., Engrs.* (C. W. Fisher, Systems Eng. Facility, Alexandria)

K. J. Rourke: from Assoc. Engr. to *Mgr., Civil and Electronic Eng.* (N. J. Rauch, White Alice Project)

J. R. Turner: from Engr. to *Ldr., Engrs.* (T. G. Rutherford, Telemetry, Timing & Firing Eng., Missile Test Project)

F. R. Zschiegner: from Installation and Modification Engr. to *Ldr., Installation Group* (N. J. Rauch, White Alice Project)

Electronic Components & Devices

D. W. Davis: from Sr. Engr., Product Development to *Mgr., Product Eng.-Photo Tubes* (Mgr., Photo and Image Tube Operation, Product Eng.-Photo Tube, Lancaster)

D. L. Roberts: from Engr., Product Development to *Eng. Ldr., Mask Manufacturing* (Mgr., Product Eng.-Color, Mask Manufacturing-Color, Lancaster)

L. B. Smith: from Ldr., Tech. Staff to *Mgr., Production Eng.* (Mgr., Manufacturing, Production Eng., Needham)

DEP Aerospace Systems Division

J. G. Colt: from Eng. Scientist, Tech. Staff to *Ldr., Tech. Staff* (C. E. O'Toole & J. B. Friedenberg, LEM, Burlington)

D. Dobson: from Ldr., Tech. Staff to *Admin., Tech. Presentation Coordination* (K. Palm, Eng. Project Admin., Burlington)

L. Funk: from Staff Eng. Scientist to *Ldr., D & D Eng. Staff* (G. Grondin, Van Nuys)

J. Hayes: from Staff Eng. Scientist to *Ldr., D & D Eng. Staff* (G. Grondin, Van Nuys)

H. Hite: from Sr. Member D & D Eng. Staff to *Ldr., D & D Eng. Staff* (E. Stewart, Van Nuys)

R. Mark: from Sr. Project Member to *Ldr., Tech. Staff* (S. S. Kolodkin, Radar & Control Eng., Burlington)

F. Marshall: from Prin. Member, D & D Eng. Staff to *Ldr., D & D Eng. Staff* (G. Grondin, Van Nuys)

D. Olker: from Sr. Member D & D Eng. Staff to *Ldr., D & D Eng. Staff* (E. Stewart, Van Nuys)

D. M. Priestley: from Sr. Project Member to *Ldr., Tech. Staff* (H. J. Woll & E. B. Galton, Sys. Support Eng., Burlington)

DEP Communications Systems Division

F. D. Kell: from Ldr., Development & Design Engrs. to *Mgr., Design & Development Eng.* (E. Hudes, Magnetic Recording Equipment Eng., Camden)

J. D. Rittenhouse: from Ldr., Development and Design Engrs. to *Mgr., Magnetic Recording Electronics* (E. Hudes, Magnetic Recording Equipment Eng., Camden)

H. Zabronsky: from Eng. Scientist, Tech. Staff to *Staff Scientist* (A. H. Kettler, N.Y. Systems Lab.)

STAFF ANNOUNCEMENTS

ECD Technical Programs: The following appointments are announced: **J. T. Cimorelli** is appointed Manager, Technical Aid and License Administration. In this capacity, Mr. Cimorelli is responsible for representing Electronic Components and Devices in the administration of all patent licensing and technical aid agreements which are negotiated by the Corporation in the areas of responsibility of Electronic Components and Devices. Mr. Cimorelli will report to **A. M. Glover,** Division Vice President, Technical Programs. **J. J. Carrona** is appointed Manager, Cryoelectric Devices Laboratory. Mr. Carrona will report to **E. O. Johnson,** Manager, Engineering.

RCA Electronic Components and Devices: The organization of the Industrial Tube and Semiconductor Division is realigned as follows, reporting to **C. E. Burnett,** Division Vice President and General Manager, Industrial Tube and Semiconductor Division: **D. J. Donahue,** Manager, Industrial Semiconductor Operations Department; **G. W. Duckworth,** Manager, Microwave-Power Devices Operations Department; **D. W. Epstein,** Manager, Conversion Tube Operations Department; **C. H. Lane,** Manager, Marketing Department; **C. F. Nesslage,** Manager, Financial Controls and Planning; **C. C. Simeral, Jr.,** Manager, Operations Services; **E. E. Spitzer,** Manager, Technical Planning; and **S. White,** Administrator, Construction and Expansion Projects.

ECD Industrial Tube and Semiconductor Division: **D. J. Donahue,** Manager, Industrial Semiconductor Operations Department, announces his organization as follows: **J. Hilibrand,** Manager, Engineering; **J. K. Johnson,** Manager, Photocell and Solar Cell Operation—Mountaintop; **P. T. Valentine,** Plant Manager, Mountaintop Plant; and **W. H. Wright,** Manager, Operations Planning and Financial Controls.

ECD Special Electronic Components Division: The organization of the Integrated Circuits Department is announced as follows, reporting to **L. R. Day,** Acting Manager, Integrated Circuits Department: **D. W. Chace,** Manager, Product Administration; **B. A. Jacoby,** Manager, Integrated Circuits Marketing; **R. D. Lohman,** Manager, Integrated Circuits Engineering; and **R. A. Wissolik,** Manager, Integrated Circuits Products Manufacturing.

Broadcast and Communications Products Division, Camden, N.J.: **W. C. Morrison,** Chief Engineer, Engineering Department announces the organization of the Engineering Department as follows: **N. C. Colby,** Manager, Communications Products Engineering; **T. M. Gluyas,** Manager, Broadcast Transmitter Engineering; **H. N. Kozanowski,** Manager, TV Advanced Development; **A. H. Lind,** Manager, Studio Equipment Engineering; **A. C. Luther,** Manager, Tape Equipment, Projector and Scientific Instruments Engineering; **R. L. Rocamora,** Manager, Antenna Engineering; **H. S. Wilson,** Manager, Microwave Engineering; and **J. E. Young,** Manager, Engineering Administration and Services.

ECD Special Electronic Components Division: The organization of the Special Project Development activity is announced as follows, reporting to **N. S. Freedman,** Manager, Special Project Development: **W. F. Lawrence,** Manager, Superconductor Materials Development; and **N. S. Freedman,** Acting Manager, Superconductor Devices Development.

DEP Communications Systems Division, New York: **E. M. Bradburd** is appointed Manager, Communications Systems Laboratory (NYC). Mr. Bradburd reports to **O. B. Cunningham,** Chief Engineer, Engineering Department, CSD.

Staff: **H. W. Phillips** is appointed Manager, Special Computer Systems Projects. In this capacity, Mr. Phillips will be responsible for directing the implementation, programming and operation of special computer systems projects, such as Operation Ballot. Mr. Phillips will report to **A. L. Malcarney,** Group Executive Vice President.

New Business Programs: **C. A. Della Bella** is appointed Manager, RCA Automation Programs, reporting to **N. R. Amberg,** Manager, Industrial and Automation Products Department.

NBC, New York: **Allen A. Walsh** was recently promoted to the position of Manager, Facilities Design and Construction, NBC Engineering Department, New York. Mr. Walsh joined NBC in 1928 as Field Engineer, later served in Engineering Development and for many years was a Project Supervisor in Audio-Video Facilities Engineering.

NEW ASD-BURLINGTON ENVIRONMENTAL LAB FEATURES NEW EQUIPMENT AND UNIQUE VIBRATION-ISOLATION

The new 5,300-square-foot ASD-B environmental engineering laboratory of the DEP Aerospace Systems Division, Burlington, Mass., was completed in January 1965. Located in the laboratory presently is one temperature-altitude-humidity chamber, one temperature-altitude chamber, two temperature-humidity chambers, one drop test shock machine, a hydraulic test stand, a precisely measured air supply, two thermal-vacuum systems, and two vibration systems with auxiliary oil slip tables. The CVC chamber, 18" dia. x 30" high, has a temperature range of —20°F to 200°F. The CVC system can achieve a bare chamber pressure of 1 x 10^{-5} torr in 5 minutes at ambient temperature, and has achieved an ultimate bare chamber pressure of 5 x 10^{-8} torr. The thermal-vacuum space simulator, 3' dia. x 4½' long, has a temperature range of —320°F to +300°F, and can achieve a bare chamber pressure of 1 x 10^{-6} torr in 14 hours at a temperature of +300°F and has achieved a bare chamber pressure of 5 x 10^{-7} torr in 4 hours at a temperature of —300°F.

The Calidyne sine vibration system is rated at a peak sine force of 1,500 pounds. The MB vibration sine-random vibration system is rated at a peak sine force of 9,000 pounds and a random RMS force of 6,500 pounds. The MB system is completely automatic, utilizing 80 filters continually for equalization for random vibration testing. The MB automatic equipment has also been rewired to provide versatility in the laboratory. The MB random console and equalizer can program the Calidyne vibration system for random vibration tests while sine vibration tests can be conducted simultaneously on the MB vibration exciter.

The ASD-B environmental laboratory is presently using an advanced concept for vibration isolation of the MB C-126 vibration exciter. The vibration exciter is mounted on a 100,000-pound reinforced-concrete block. The block, with the exciter, is in turn suspended by fourteen servo-controlled pneumatic isolators (air springs), making the suspension system for superior to conventional isolation systems. This system has a damped natural frequency of 2¼ c/s with added benefits of static stability, automatic stiffness match, automatic and precision leveling independent of the supported mass. This system will not allow vibrations to be transmitted to the rest of the building preventing possible building damage and preventing any errors to sensitive electro-optical equipments and preventing vibratory discomfort to personnel. The Calidyne 174 vibration exciter is also isolated by the same means by suspending a 12,000 lb. concrete block on four servo-controlled pneumatic isolators.

An overhead wire trough encircles the laboratory so that any measurements from any of the facilities can be recorded in an isolated instrumentation room.—*J. G. Colt*

FINAL VOLUME RELEASED IN MEDICAL ELECTRONICS SERIES PREPARED FOR USAF BY SERVICE CO.

The last in the three-volume series of texts on medical electronics, *Techniques of Physiological Monitoring*, was recently completed for the Air Force Aerospace Medical Research Laboratories by the Technical Publications Facility, RCA Service Company.

These texts bridge the gap between physiologists and electronic engineers by bringing together in a single reference information, garnered from hundreds of authenticated sources, and written in concise language understandable to both the scientist and the nonprofessional.

The emphasis in these three volumes has been on practical aerospace applications. Volume I, *Fundamentals* (120 pages), was printed by the Air Force in 1962. This was followed in 1963 by Volume II, *Components* (256 pages), and in late 1964 Volume III, *Systems* (144 pages).

Copies of these volumes can be purchased from the *Office of Technical Services, Department of Commerce, Washington, D.C., 20230.* Each volume should be identified by the Air Force report number, AMRL-TDR-62-98, followed by the appropriate volume number (I, II, or III) in parenthesis.

CITY BUYS 300 RCA VE-DETS

About 300 RCA Vehicle Detectors (VE-DETS) are being installed by San Jose, Calif., as an initial step in the city's planned automated traffic control. Originally, the information from the VE-DETS will be collected for analysis of San Jose's traffic patterns and problems; eventually, the data will be fed to a computer controlling the stop-and-go lights in San Jose's busier traffic areas.

The San Jose project is believed to be one of the largest installations of electronic vehicle detectors ever made. About half of the 300 units are replacing previously installed competitive units.

VE-DETS are made by the RCA Industrial and Automation Products Department, Plymouth, Mich. Basically, a VE-DET consists of a coil and associated circuitry, buried in the road, that provides a signal whenever a relatively large mass of metal (an auto or truck) passes over. (For complete details, see RCA ENGINEER, Vol. 10-5, Feb.-Mar. 1965, article by E. C. Donald).

RCA Industrial and Automation Products has also adapted VE-DETS for detecting railroad cars in automated freight switching yards, and recently sold 40 units to a major eastern railroad.

IEEE ANNOUNCES NEW JOURNAL OF QUANTUM ELECTRONICS

A new monthly journal devoted to describing the latest advances in quantum electronics will be published in April 1965 by the IEEE. In the new *IEEE Journal of Quantum Electronics*, editorial emphasis will be placed on the physics of quatum electronic devices, such as masers and lasers, and on associated techniques such as modulation, detection, and nonlinear optical effects. Initial circulation will be free to the members of the IEEE Electron Devices and Microwave Theory and Techniques Groups, a selected list of others active in the field of quatum electronics, as well as to present subscribers to the *Transactions* of these Groups. Starting with the July 1965 issue, a subscription price will be charged: IEEE members, $5.00 per year; libraries and colleges, $12.75; and nonmembers, $17.00. A special affiliate rate of $9.50 per year is available to members of societies such as AIP, ACS, AIChE, and ES.

SCIENCE TEACHERS HOLD WORKSHOP AT RCA LABS

Lasers and masers were the topics of discussion at a science teacher's workshop held at RCA Laboratories on April 2 under the sponsorship of the Princeton Area Science Education Committee (PASEC).

Max D. Blumenfeld, of the American Cyanamid Company, who is Chairman of PASEC, presided at the workshop sessions. **H. W. Leverenz,** Associate Director, RCA Laboratories, welcomed the workshop participants to the David Sarnoff Research Center.

Dr. Henry R. Lewis, Head of the Quantum Electronics group of the Electronic Research Laboratory, served as chairman of the workshop and began the discussions with a talk on the stimulated emission of electrons, the basis of both masers and lasers. Four other staff members of the Electronic Research Laboratory—**Dr. Robert J. Pressley, Dr. Jacques I. Pankove, Dr. Karl G. Hernqvist,** and **Dr. Charles H. Anderson**—conducted the morning sessions on optically pumped lasers, injection lasers, gas lasers, and masers.

Mr. J. P. Epperson, of the Western Electric Research Center in Princeton, discussed laser applications at the afternoon session. The workshop concluded with the presentation of a film on lasers made by the Princeton Report, Inc. The film, which is narrated by Chet Huntley, contains several sequences that were made at RCA Laboratories.

The workshop program at RCA Laboratories was arranged by **Dr. J. S. Donal,** Administrator, Special Programs, and **Harry L. Cooke,** Administrator, Technical Relations, both of the RCA Laboratories staff.

ECD SUPERCONDUCTIVE GROUPS CONSOLIDATED AT HARRISON

The ECD Special Electronic Components Division has consolidated its Superconductive Materials and Devices operations at Harrison, N.J. An affiliated research laboratory has been moved from RCA Laboratories, Princeton, N.J., to Harrison, N.J. where the activity's pilot production facility is located. The move to larger quarters at Harrison was necessary because of expanded activities as well as for close liaison between the two functions, according to **Norman S. Freedman,** Manager Special Projects Developments, which includes the superconductive group. Superconductive Materials and Devices produces vapor-deposited niobium stannide superconductive ribbon for construction of superconductive magnets as well as selling it to others. The activity is building a 150-kilogauss magnet with a 6-inch bore under contract to NASA, and plans to announce shortly the availability of a 100-kilogauss research magnet with a 1¼-inch bore.

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Correction: In the last issue of the RCA ENGINEER (April-May 1965, Vol. 10-6), in the article "Speech Recognition using Artificial Neurons," **H. Zadell** (DEP Applied Research, Camden) should have been included as a co-author, along with **M. B. Herscher** and **T. B. Martin.** His name was inadvertently omitted from the original manuscript when the article was submitted.

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RCA ENGINEER

A TECHNICAL JOURNAL PUBLISHED
BY PRODUCT ENGINEERING.
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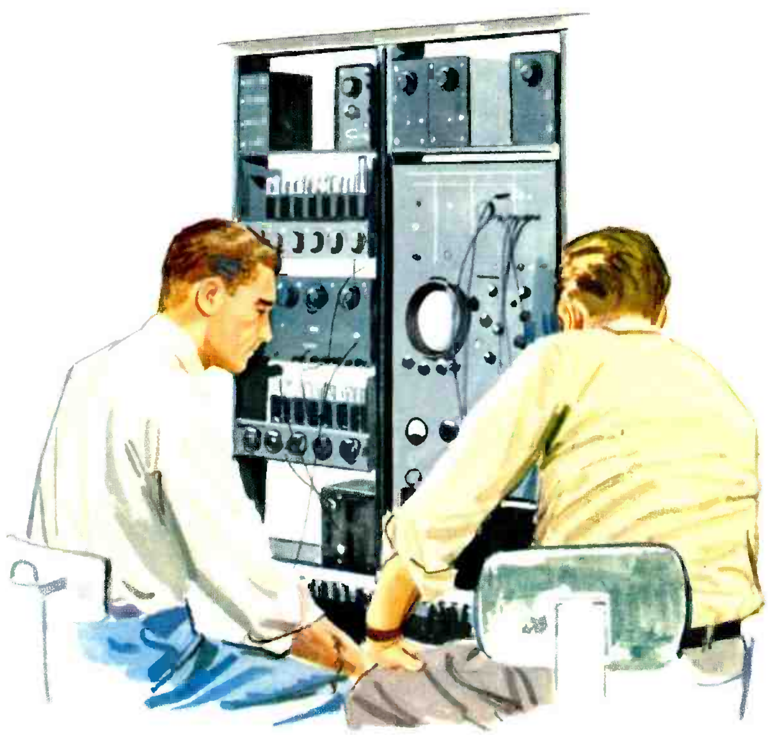

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