VOLUME 1 NUMBER 1 JANUARY 1964

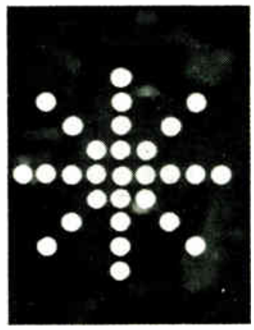
IEEE spectrum

articles

departments

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS INC.

the cover



The pattern reproduced on the front cover results when light from a gas laser is projected through a series of lenses between which the aperture shown at the left has been placed. The experiments were performed by R. E. Hopkins, D. Dutton, and M. P. Givens of the Institute of Optics, University of Rochester, and described in their 1963 NEREM paper. For a detailed description of some other work in coherent light diffraction, see the article by W. H. Huntley, Jr., in this issue, page 114.

IEEE SPECTRUM is published monthly by The Institute of Electrical and Electronics Engineers, Inc. Headquarters address: Box A, Lenox Hill Station, New York, N.Y. 10021. Cable address: ITRIPLEE. Telephone: 212—PL 2-6800. Published at 20th and Northampton Sts., Easton, Pa. **Change of address** requires thirty days notice to IEEE Headquarters. **Annual subscription:** IEEE members, first subscription included in dues, one additional subscription $13.50. College and public libraries, $13.50 in U.S.A. and Canada, $14.50 elsewhere. Others, $18.00 in U.S.A. and Canada, $19.00 elsewhere. Single copies: members, one additional copy $1.00, college and public libraries, $1.50 in U.S.A. and Canada, $1.75 elsewhere. Others, $2.00 in U.S.A. and Canada, $2.25 elsewhere. **Editorial correspondence** should be addressed to IEEE SPECTRUM at IEEE Headquarters. **Advertising correspondence** should be addressed to IEEE Advertising Department, 72 W. 45 St., New York, N.Y. 10017. Telephone: 212—MU 2-6606.

vices in the communications room, a demonstration of how the news is edited, the mechanical operations required to put the paper on the street, and look at the composing room.

Consolidated Edison System Operations Center, New York, N.Y. (Tuesday Afternoon, Thursday Afternoon) This trip will consist of a tour through Con Edison's new System Operations Center. The Center will be viewed from a special area constructed for that purpose and the instruments and operations will be seen at close range on a closed-circuit television set.

Radio City Music Hall, New York, N.Y. (Wednesday Morning) Backstage facilities, revolving sectionalized stage, elevating orchestra pit, motorized curtains, and the electric and mechanical controls for stage and lighting effects will be inspected. No women or children are permitted.

Holophane Light and Vision Institute, New York, N.Y. (Wednesday Afternoon) At the newly revised Institute, demonstrations will be given showing effects of quantity of light; light control to reveal depth and texture; how photometric curves are made; and other details. Refreshments will be served.

Ravenswood Generating Station, Con Edison, New York, N.Y. (Wednesday Afternoon) The two Con Edison units at Ravenswood Station in Long Island City, each with a name-plate rating of 363 mw and operating capability up to 425 mw, will be open for inspection.

Digital Computer Control Center, Philadelphia Electric Co., Philadelphia, Pa. (Thursday Morning) Inspection will be made of a system of completely solid-state design that uses no motors, servos, slidewires, or vacuum tubes.

Site of 1964 World's Fair, Flushing Meadow, N.Y. (Thursday Afternoon) A preview model of the Fair, scheduled to open in April 1964, will be viewed and the facilities under construction may be toured. The electrical distribution system designed and developed specifically for the Fair will be explained.

A special feature of this year's Winter Power Meeting will be a students' session scheduled for Monday afternoon, February 3. A program has been arranged for the student engineers on the so-called glamor area of computer applications, control and communications, atomic and MHD energy conversion, and system planning. Speakers will be young engineers, no more than ten years out of college. Student participation in the discussion will be encouraged.

Tickets for all events, including the ladies' activities, will be available at the registration desk, but the Hospitality Committee is inviting advance registrations for all social activities.

Advance registrations may be obtained by writing to Julius Bleweis, *Electrical World*, 330 West 42 St., New York, N.Y. Checks for all social functions may be made payable to William West, Treasurer.

Delegates are urged to make room reservations for the Winter Power Meeting as early as possible. Requests for reservations should be addressed to Philip Roberg, Reservations Manager, Statler Hilton Hotel, Seventh Ave. at 33 St., New York, N.Y. 1001. Room rates are as follows: Single room $10 to $18; Double room $14 to $22; Twin-bed room $18 to $25.

The members of the Winter Power Meeting Committee are: J. H. Kinghorn, general chairman; E. J. Merrell, vice-chairman; C. Dorsa, secretary; E. C. Day, Headquarters representative; W. West, treasurer; C. A. Woodrow, representative, Power Division; S. H. Grim, representative, New York Section; J. C. Derse, local arrangements; D. T. Braymer, publicity; R. T. Weil student activities; A. P. Fugill, technical program; C. T. Hatcher and D. M. Quick, Members-at-Large.

Technical program given. The tentative technical program for the Winter Power Meeting follows:

MONDAY, FEBRUARY 3

9:30 a.m. Sessions

Insulated Conductors—1
Status and Potential of Energy Conversion Devices for Power Application
Lightning Arrester Applications and Proposed Standards
Transformers—1
H. V. Systems
Switchgear—1
Student—Faculty

TUESDAY, FEBRUARY 4

9:30 Sessions

Foreign Practices
Switchgear—2
Transformers—2
EHV Line Design
Electric Space Heating and Air Conditioning—1
Insulated Conductors—3

2:00 p.m. Sessions

Large Turbogenerator Application Problems
Induction Machines
Switchgear—3
Transformers—3
500 kV Line Design
Electric Space Heating and Air Conditioning—2

WEDNESDAY, FEBRUARY 5

9:30 a.m. Sessions

Forces Affecting Power Engineering
Relays
Synchronous Machines
Switchgear—4
High-Voltage Phenomena
Conductor Vibration

2:00 p.m. Sessions

Power Plant Design
Cables for Communication and Coupling Capacitor Potential Devices
System Capacitor Applications and Planning
Synchronous Machines and Inductor Machines
Residential Wiring
Student—Faculty

THURSDAY, FEBRUARY 6

9:30 a.m. Sessions

Insulated Static Wires and Microwave for Communication
Outage Data Analysis for Transmission and Distribution System Planning
Panel Discussion
General Rotating Machine Theory
Substation Design Standardization Methods and Techniques—1
Switching Surges—1
H. V. Corona and Radio Noise
Corona and Breakdown Phenomena

2:00 p.m. Sessions

Power Plant Control and Protection
Computer Applications to Network Analysis Solutions
D-C Machinery
Substation Design Standardization Methods and Techniques—2
Panel Discussion: Substation Design Standardization Methods and Techniques
Switching Surges—2
Test Methods for Thermal Evaluation and Quality Control of Electrical Insulation

FRIDAY, FEBRUARY 7

9:30 a.m. Sessions

Application of Probability Methods
Fractional Horsepower Motors
Capacitors
Towers, Poles and Conductors
Substations

5th National Winter Convention on Military Electronics due in February

The 5th National Winter Convention on Military Electronics will be held February 5–7 in Los Angeles, Calif., at the Ambassador Hotel. The convention is sponsored by the IEEE Professional Technical Group on Military Electronics and the Los Angeles District of IEEE. The classified sessions of the convention are sponsored by the U.S. Air Force Systems Command.

The February 6 banquet speaker will be Maj. Gen. F. H. Britton, director of research and development, U.S. Army Materiel Command. The February 5 luncheon speaker is to be announced.

Opening panel described. The February 5 opening panel for the convention will discuss some aspects of the theme

"Weapons Systems Procurement," with Dr. Eugene Fubini as chairman and moderator. Dr. Fubini is a deputy director for research and engineering, Office, Assistant Secretary of Defense.

Dr. Fubini's panel members include: Lt. Gen. Dwight Beach, Commanding General, Army Combat Development Command; Lt. Gen. Thomas Gerrity, Deputy Chief of Staff, Systems and Logistics, U.S. Air Force; G. C. Bannerman, Deputy Assistant Secretary of Defense (Procurement), Office Secretary of Defense for Installations and Logistics; R. E. Horner, senior vice-president and general manager, Northrop Space Systems Lab., and J. N. Davis, Deputy Assistant Secretary of Defense (Weapons Acquisition and Industrial Readiness).

Registration fees are $10.00 for Members of IEEE and $12.00 for nonmembers of IEEE. Registration fees include one copy of the *Convention Proceedings*. Military and Civil Service employees may register for $3.00 (this does not include a copy of the *Proceedings*). There is no charge for Military and Civil Service employees to attend the exhibits.

Additional copies of the *Proceedings* will be sold at the convention for the price of $7.00.

Exhibitors named. Industry leaders exhibiting equipment will include Western Electric Co., Clary Corp., International Telephone & Telegraph Corp., General Dynamics, Seiscor-Seismograph, Singer Co. (Metrics Div.), Phelps Dodge, Space Technology Labs., North American Aviation, Autonetics Div., Lockheed Missiles & Space Co., Westinghouse Electric Corp., Bendix-Pacific Div., and Automation Development Corp. Services exhibits will be shown.

The general chairman of the convention is C. D. Perrine, Jr., executive vice-president, General Dynamics–Pomona. The vice-chairman is H. J. Delaney, Filtron Co., Inc., and the Technical Program chairman, Dr. N. A. Begovich, vice-president, Hughes Aircraft Ground Systems.

The Advisory Committee includes: J. M. Bridges, Research and Engineering, Dept. of Defense; S. W. Crosby, Assistant to the Deputy Secretary of Defense, DOD; Rear Adm. E. E. Fawkes, Assistant Chief for Research, Test and Evaluation Dept., U.S. Navy; Maj. Gen. M. C. Demler, Cmdr., Air Force Service Command Research & Technology Div., U.S. Air Force; Maj. Gen. F. H. Britton, U.S. Army Materiel Command; Maj. Gen. D. R. Ostrander, Cmdr. Aerospace Research, USAF; Rear Adm. J. H. McQuilkin, BuShips Research & Development, USN; Maj. Gen. F. F. Uhrhane, U.S. Army (Retired), and Milton Fryer, Jr., North American Aviation.

The usual cocktail reception before the banquet and the full ladies' program are planned.

Registration material may be obtained by writing the Los Angeles District IEEE Office, Suite 1920, 3600 Wilshire Blvd., Los Angeles, Calif. 90005.

Program sessions listed. The tentative technical program for the convention follows:

WEDNESDAY, FEBRUARY 5

2:00 p.m. Sessions

Command and Control (unclassified)
Microelectronics (unclassified)
Anti-Submarine (confidential)
Air Defense (secret)

THURSDAY, FEBRUARY 6

9:00 a.m. Sessions

Radar Technology (unclassified)
Guidance & Control (unclassified)
Nuclear Radiation Effects (unclassified)
Space and Communications (secret)

2:00 p.m. Sessions

Reconnaissance (unclassified)
Reliability and Maintainability (unclassified)
Ballistic Missiles (secret)

FRIDAY, FEBRUARY 7

9:00 a.m. Sessions

Program Management, Control & Evaluation (unclassified)
Radiation Effects (secret)
Displays and Human Factors (unclassified)

2:00 p.m. Sessions

Communications (unclassified)
Air and Ballistic Missile Defense (unclassified)
Radar (secret)

National Convention on Military Electronics features discussion on human and computer intelligence

During the recent National Convention on Military Electronics in Washington, D.C., a panel discussion on "Human and Computer Intelligence" was held. The following report is a condensed and edited version of that discussion. Formal remarks of the panelists are immediately followed by an open discussion.

David Mck. Rioch, M.D., *Director, Division of Neuropsychiatry, Walter Reed Army Institute of Research*

In this most interesting period in which to live, we all assume that we know what human intelligence is but few of us feel that we know what computer intelligence is.

Computer intelligence is an area of considerable anxiety for some people; they tend to deal with it by saying: "They have machines that they say are intelligent, but I don't believe it. They don't feel." Others think: "Now the millenium is about to arrive because we can develop machines that think." Either of these attitudes brushes aside the even more fundamental problem that we still cannot adequately define human intelligence.

In any event, we're moving rapidly into a new era. We feel threatened by this situation and need greater clarification of what machines can and cannot do, how we can control them, how we can use them adequately, and what changes we ourselves may have to undergo to live with them.

The primary difference between computer progress and anything else we care to call progress is that the computer has the ability to do some planning. Unfortunately, however, we don't yet know how to put many planning problems into the computer. This is because we don't have an adequate idea of what much of the human thinking process is in terms that would help us to program the computer.

J. Presper Eckert, *Vice President,* UNIVAC, *Divison of Sperry Rand Corp.*

After 17 years, I've finally been forced to adopt the definition that thinking is that which a computer cannot do. This definition is very workable since it

Only one electronics manufacturer* in the world can make this statement:

"We deliver the following quality products *from stock:* bench instruments; closed-circuit television systems (environmental, miniaturized, industrial); DC data amplifiers (wideband, narrowband, differential, solid state); DC preamplifiers; digital comparators; digital programers, digital translators; digital voltmeters (solid state, mercury-wetted, Zener reference, stepping switch); meter calibrators; power supplies; ratiometers; thermal transfer standards, and voltage standards (AC, DC, DC programable)."

FOR TECHNICAL INFORMATION, CALL US AT:

NORTH AMERICA

Ala., Birmingham	205-534-1648
Ala., Huntsville	205-534-1648
Ariz., Phoenix	ENTERPRISE 6700
Ariz., Tucson	ENTERPRISE 6700
Calif., Beverly Hills	213-655-5200
Calif., Los Angeles	213-655-5200
Calif., Palo Alto	415-323-2466
Calif., San Diego	714-277-6700
Calif., San Francisco	415-323-2466
Canada, Montreal	514-684-3000
Canada, Ottawa	613-722-7658
Canada, Toronto	416-293-3161
Colo., Denver	303-388-4391
Conn., Bridgeport	203-368-4582
Fla., Orlando	305-241-1091
Ida., Idaho Falls	206-725-7727
Ill., Chicago	312-676-1100
Ind., Indanapolis	317-356-4249
La., New Orleans	504-943-5617
Md., Baltimore	301-656-3061
Md., Bethesda	301-656-3061
Mass., Boston	617-658-9171
Mass., Wilmington	617-944-3930
Mich., Detroit	313-357-3700
Minn., Minneapolis	612-545-4481
Mo., St. Louis	314-966-3646
Nev., Las Vegas	ENTERPRISE 1-5051
N. C., Greensboro	919-273-1918
N. J., Clifton	201-773-6160
N. M., Albuquerque	505-255-9362
N. Y., Baldwin	516-223-8000
N. Y., New York City	516-223-8000
Ohio, Cleveland	216-442-8080
Ohio, Dayton	513-298-7573
Okla., Tulsa	918-627-1515
Ore., Portland	206-725-7727
Penn., Philadelphia	215-877-7071
Penn., Pittsburgh	412-884-5515
Tex., Dallas	214-235-4541
Tex., Houston	713-529-5292
Utah, Salt Lake City	801-328-3101
Wash., Seattle	206-725-7727

THE WORLD

Argentina, Buenos Aires	33-7770
Australia, Melbourne	42-1216
Austria, Vienna	54-7585 Serie
Belgium, Brussels	37-31-30
Denmark, Copenhagen	ASTA 1575
England, Farnborough	HANTS 3000
Finland, Helsinki	13505
France, Paris	PYR 48-40
Germany, Munich	59-51-09
Holland, Rotterdam	35380
India, New Delhi	57131
Italy, Milan	321-544
Japan, Tokyo	281-6811
New Zealand, Christchurch	62-254
Norway, Oslo	42-99-93
Portugal, Lisbon	672161-5
Sweden, Stockholm	65-28-55
Switzerland, Bern	(031) 37866

* COHU ELECTRONICS, INC., Kin Tel Division, 5725 Kearny Villa Road, San Diego, California 92112, Phone: 714-277-6700

J. P. Eckert

changes from year to year as computer progress is made.

For example, one of the things a computer cannot do well at present is to recognize patterns no matter whether these patterns are in the form of handwriting, numbers, letters, mountaintops, or submarine periscopes.

On the other hand, computers have shown themselves to be very efficient at solving problems of complexity if we have some of the formulas. But the problem of getting the formula—the problem of perplexity—has not received much attention. Most of the formulas and ideas we're using now are over 100 years old. Others, such as linear programming, were invented about 20 years ago but were not used until recently.

A human brain is believed to contain about 10 billion cells. We don't know whether these cells are all logic elements, or partly logic and partly memory elements.

The largest computers built so far have only about 100 000 logic elements. Most computers have only about 10 000. The largest have no more than a few million bits of fast memory.

By any criterion, computers fall far short of the capacity the human brain apparently has at its disposal to solve problems. Therefore, we can safely assume that at present computers cannot provide sufficient complexity to solve the problem even if we know the formulas.

The matter of speed seems to offer promise. We can build computer elements which can work in a few nanoseconds. The elements in the human brain work in a few milliseconds at best. Compared to the human brain, computers are something of the order of one million or more times faster but about the same order of magnitude short on the number of elements needed.

What we seem to need is a general theorem for exchanging speed with complexity. As yet nobody has discovered any general theorem for doing so, although there are certain techniques such as breaking complex problems into a series of less complex steps that are sometimes useful. But most problems such as pattern recognition do not allow this technique to be used. Instead, we need some sort of time-sharing mechanism in which this is possible.

Suppose, for example, we want a system containing two million logic elements and for convenience we divide these elements into two fields each containing one million elements. Two fields will enable us to bounce information back and forth between them, making a logical transformation each time.

Let us suppose that each of these fields is made up of an array of 1000 by 1000 inexpensive elements. One economical approach might be the use of a sheet of material containing an array of one million optical elements. Each optical element would give no response when hit by one element of light but would respond when hit by two or more. These elements are also assumed to be capable of electric readout by a simple conductive grid of 1000 by 1000 conductors.

Assume we arrange the electro-optical elements in a rectangular array so that they are at the intersections of a 1000 by 1000 array of conductors. Assume that time pulses can activate one edge of the array, a conductor at a time in sequence, and cause information to be read out in groups containing up to 1000 impulses at a time from the conductors making up the other dimension of the array.

Thus far, I have described only a memory threshold device, activated by light, and capable of being read out in a serial parallel fashion. We now need a means for obtaining a logical transformation.

This can be done by taking the 1000 signals from the array and using them to drive 1000 small light projectors—each of which contains a lens and a negative or pattern which excites certain selected spots in the other array field of a million elements. A second set of 1000 time-sequencing light projectors will select those spots which are to be affected at a particular time in coincidence with light from the first set of projectors. In the second projector set, just one will be turned on at a time (in contrast to the first set of projectors in which many may be turned on at any given time) to control the time-sharing logic sequence of the information transformation.

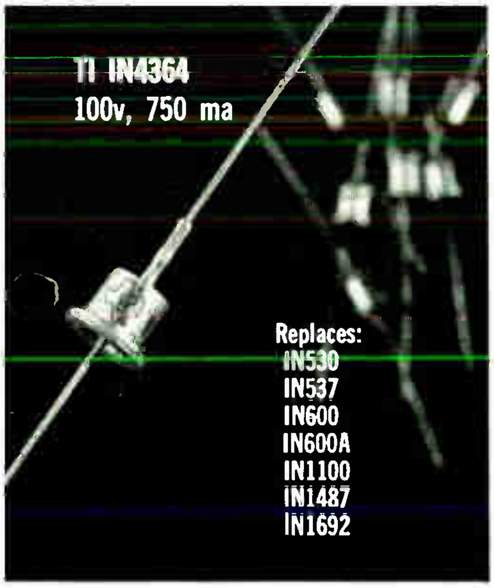
The mechanism by which the coincidences of light from the two sets of projectors control a particular electrical optical element can be based on a threshold effect or an effect which requires two different frequencies or colors of light to cause its operation. With coherent light it might even depend upon the phase relation of the light from the different sets of projectors. Electric signals applied to the time-sequencing conductors (one edge) of the first array cause it to transmit information through the first set of light projectors to the second array and, in a 1000-step sequence, determine which elements of the second array are to be affected at any one time. Thus, a complex and highly flexible logic transformation, similar to that performed between clock phases of a conventional computer in one time period, will be performed—but it will require 1000 time periods. The payoff is that economically it may be many times more complex.

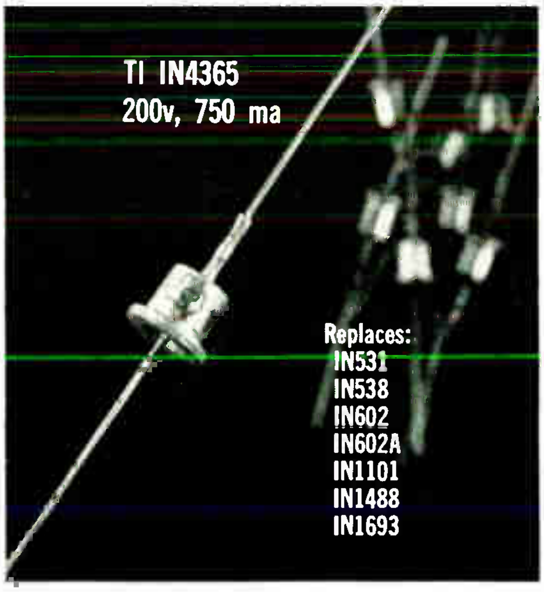
Normally there will be one spot in an array for each diode or similar logical "input" element being replaced in a present-day logic structure. The optical flexibility of this system allows complete freedom as to how a spot in one area affects spots in the other array without the inflexibility of a maze of semiconductors and wires. In fact, a few photographic negative plates placed in the optical projector system of this device completely describes the logical system. The rest of the optical and electrical system is, in itself, a repetitious mechanism having no specialized logical properties.

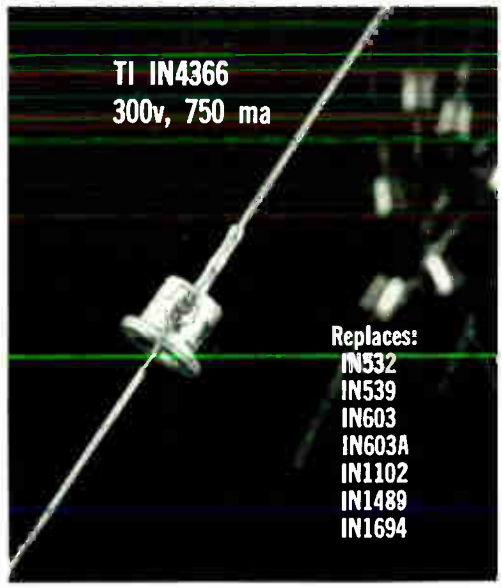
A complete system might contain just two electro-optical arrays or sheets and an associated timing circuit for activating 2000 conductors in simple sequence and 4000 light projectors, 2000 in each array, with their associated negatives. Such a system would replace over 2 million semiconductors and their mass of interconnecting wire. An element like this would greatly enhance our ability to build an artificial intelligence, since it provides the means to exchange some of the speed we have now for a degree of complexity which we cannot achieve economically at present.

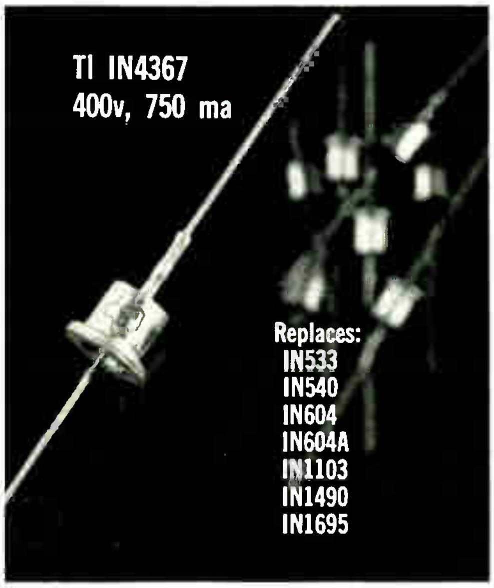
Winston E. Kock, *Director, Research, The Bendix Corp.*

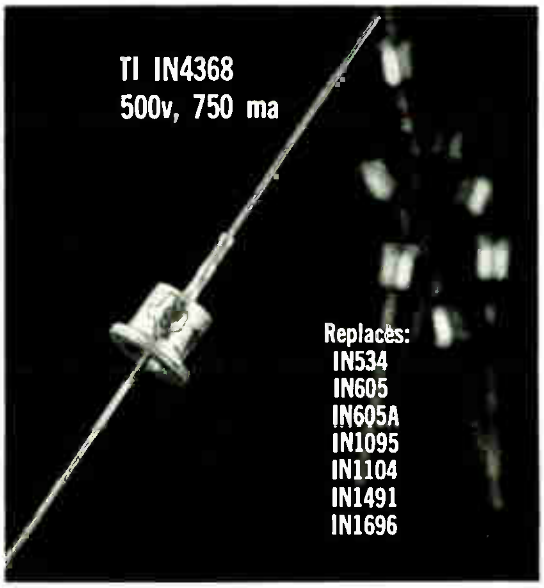
Consider the interface between computer operations and the central nervous

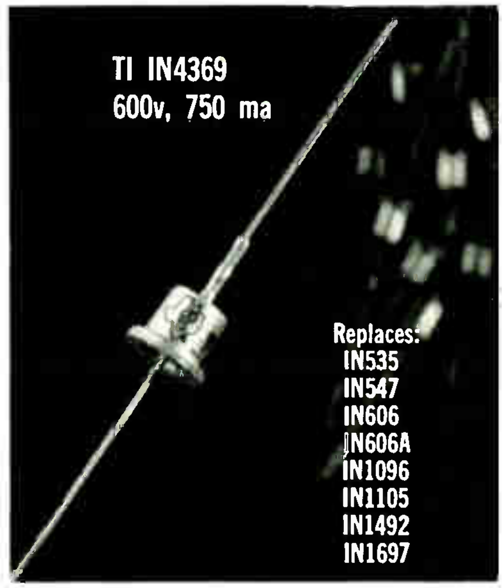












NOW... six rectifiers replace forty-three

Six new Uni-Versatile* rectifiers combine best specs, best prices of 43 older type

Now you can directly replace 43 conventional general-purpose rectifiers with six new-generation diffused-junction rectifiers from Texas Instruments. The result: better performance, higher reliability, and significant inventory savings . . . at a price equal to or lower than you are now paying.

Performance is improved. Uni-Versatile rectifiers meet or exceed all the specifications of even the most expensive older devices. In no case is the over-all guaranteed performance of a Uni-Versatile unit matched by its older replaceable counterpart. Through important advances in diffusion technology, low forward voltage drop (V_F = 1.0v @ I_O = 0.5 a) has been combined with exceptionally low leakage (1.0 μa @ 25°C, 100 μa @ 150°C, full-rated voltage). Greater efficiency and long-term reliability result. Diffused-junction construction provides high, 35-amp surge-current capability. Reliability is further enhanced by an all-welded, hermetically sealed package.

Costs are reduced. Parts standardization with Uni-Versatile rectifiers offers you significant savings potential in reduced inventory and simplified purchasing. You realize direct savings in component cost as well in 30 of the 43 replacements; in the remaining 13, prices are equal.

Ask your TI sales engineer or authorized distributor for full information on Uni-Versatile silicon rectifiers. Or write for detailed data sheets.

** Trademark of Texas Instruments Incorporated*

TEXAS INSTRUMENTS INCORPORATED
SEMICONDUCTOR-COMPONENTS DIVISION
P. O. BOX 5012 • DALLAS 22, TEXAS

SEMICONDUCTOR PLANTS IN BEDFORD, ENGLAND • NICE, FRANCE • DALLAS, TEXAS

20233

Dr. W. E Kock

system, particularly in the biophysical aspect wherein electronics techniques have reproduced a similarity to our own nervous system. There are artificial nerves which cause impulses to be regenerated continuously. There are also electronic solid-state neurons which can be excited and inhibited as can our own neurons. This inhibition is partially responsible for the sharply defined frequency response in the basilar membrane of the human ear cochlea. In the Haas effect, if the same audible signals are issued from two loudspeakers that are separated, and if the signal issuing from one is delayed by 25 milliseconds, our ears almost completely ignore this delayed sound. Because of the inhibition generated in the median geniculate, the localization properties of both ears are destroyed. Thus, we believe that all the sound is coming from the undelayed source.

Our binaural localization properties have a counterpart in the detection processes. One such process tries to detect a "noise-like" sound in the presence of a tremendously large, omnidirectional noise. Two spaced sensors, similar to our ears, multiply and integrate signals. The longer the integration time, the deeper we can "dig into" the noise to extract this desired noise-type signal.

The ear's frequency-analyzing properties have been copied in the detection process which seeks single-frequency signals "buried" in the noise. This aural property permits us to detect and identify an oboe solo in the sea of musical noise created by the rest of the symphony orchestra. A filter, modeled exactly on the known properties of the ear's basilar membrane, has been built. It could indicate the presence of a very weak signal frequency in the noise.

Human memory is apparently a result of nerve loops comparable to tape loops. The neurons cause the memorized information to circulate continually and repetitively. We tap this loop whenever we wish to recall information. The *deltic* computer element is comparable to the memory loop. Here, a digitalized signal is inserted in a quartz delay line which closes back on itself; and the signal, if not altered, circulates continuously around the loop. The process involves changing periodically so that a new signal is inserted into the loop, then analyzed.

The electronicists have combined two human abilities—the ear's analysis process and the eye's integration ability.

If we replace the eye with an electronic integration system, we should have not only the capability of the ear in the original analysis procedure, but also the ability of the eye in integration.

I have been trying to get computers to do things previously done only by people. There are two sets of studies on artificial intelligence. One set attempts to understand how people do things and to use computers to implement this understanding. The second approach is to have computers do these things irrespective of whether or not they are done in the same way as people, from the viewpoint of developing useful tools. My interest has been in this second area.

The brain seems to be composed of neurons. The brain can do the complicated process of studying their properties. Therefore, if we build a simulated brain, we shall achieve a device that can do the same things as the brain.

In another approach, we can analyze the problems that the brain solves—irrespective of the way it solves them.

There's a trite analogy to these two different approaches. In the early history of aircraft development, people tried to simulate the flight of birds. They said: "A bird can fly; therefore, let's build a mechanical bird, and it will fly." But, it was not until people started the study of aerodynamics that we were able to develop airplanes. Now we have made studies on the aerodynamic aspects of a bird's flight. We have discovered that there are many things birds know—and we don't.

Arthur L. Samuel, *Research Consultant, International Business Machines Corp.*

Consider a typical problem the brain does well and machines do very poorly.

Dr. A. L. Samuel

In the game of checkers there is no known algorithm or formula by which you can get a computer to follow a system of rules to win. People also don't know such rules, yet they play the game very well. How is this done? We believe people do it through *heuristic* procedures. These are "rule-of-thumb" procedures, which apparently work. If we want computers to do these tasks, we must develop techniques of solving these heuristic approaches to problems.

The first is the *problem of immensity*. Any strategic problem in chess or checkers is so complicated that if we attempt it by the "exhaustion" process of looking back from the end of the game, considering every possible first play and every counter replay, we find that the number of possible moves becomes astronomical toward the conclusion of the game. To solve for the first move in checkers by this procedure would require more time than the total history of the universe for the fastest conceivable computer! Yet, people can do these things very well by the use of the "three I's"—*intuition, imagination,* and *instinct*.

The next problem is that of the "gestalt"—or ability. The gestalt is evident in the pattern recognition problem. Infants develop abilities to recognize patterns. They can distinguish people from inanimate objects. Nobody tells them there are two classes of things, yet they quickly form this concept. All the tasks that we want computers to do involve the formation of concepts. People seem to have this ability, but we do not know how to get computers to acquire it.

The problem of locating memory information is another thing that retards us in getting computers to do complicated human tasks. People have an *associative* memory; computers have an *addressable* memory. One must know where a particular bit of information is stored in order to retrieve it. There are many designs for the creation of associative memories, but all of these suggested devices are primitive compared to the ability of the human brain in recalling information. For instance, when you attempt to recall a name, the oddest bits of analog information assist you.

When we want computers to do human tasks, we find that the limitations are in people's abilities to understand what they're asking the computer to do, and to express what they want done in imperative statements. The computer is a "giant moron" rather than a "giant brain." It has two characteristics not shared by people—fantastic speed and accuracy—and that's all.

Computer programs are composed of simple imperative statements. We're trying to replace a complicated preliminary programming process by a sequence of these statements. If we want computers to be more clever than humans, and to do things that we cannot do, some of us will have to be more clever than average in order to write such computer programs.

Norman Zachery, *Director of Systems Engineering, Space and Information Systems Division, North American Aviation*

Norman Zachery

My background is in the so-called software area of computing, particularly mathematics and programming. Since it is difficult, if not impossible, for anyone with this background to give a *short* dissertation on such a subject as human and computer intelligence, I will confine my remarks to some aspects of management problems in the computer field. I have no difficulty at all in summarizing my knowledge of management theory in less than 10 minutes.

In keeping with the general nature of our topic, I will attempt to keep my discussion of management problems equally "sweeping"; hence, I will not comment on specifics, but only on broad generalities.

Time and again the disparity between the fantastic growth rate in the speed of computers and the very limited growth of our ability to develop a theory for use in the computer has been demonstrated. To examine this statement more closely, let us look at the various functions we have asked the computer to perform in respect to human intelligence. These functions fall into three basic classifications. The computer can assist, cooperate with, or replace human intelligence. To date, the computer has been successful in only the first of these three. Our ability to compute, to undertake numerical approximations, and to store and recall information has literally exploded. In reference to the third classification, it is important to remember that in any part of the advance publicity given to computers' "thinking," it is not clear that any real success in this area is or ever will be possible.

From the first and third areas, let us go to a discussion of the second area—the area of human and computer intelligence working together (i.e., of the man-machine complex). Perhaps the most critical function performed by man in any man-machine complex is that of management. If the argument for the use of the computer as an aid to intelligence has any basic premise, it is as an attempt to reduce intelligence to a set of rules which can be placed on a computer. If management philosophy has a basic tenet, it is that the core of the manager's job is not reducible to a set of rules. The man-machine complex then is an attempt to combine the ability of a computer, in handling those aspects of a problem which can be reduced to rules, with the ability of man to cope with the problems that are not reducible to rules. Viewed in this light, it is apparent that the closest possible cooperation between the inanimate computer and the (presumably) animate manager must be established in a successful man-machine operation.

In order, therefore, to develop this concept of the man-machine function, managers must take a more active part in the design of the basic systems. As of today, management in general has not been so involved. For example, in the military field, there is an application which goes by the name of "command and control." Up to now, the basic conceptual developments in this field has come primarily from the technicians rather than from the military managers; yet the command and control problem is one of the most difficult facing us today, and one which can be resolved, in my opinion, only by a joint approach with computer systems designers and top-echelon military officers working together.

There are two conclusions which I would like to draw:

1. Further development in the field of computer intelligence hinges more on the education of various management levels than on improvement in computer hardware and software techniques.
2. To be optimistic about developments in the field of computer intelligence, because I believe that management generally is becoming more aware of its role and is willing to act intelligently in using computer intelligence.

Panel Discussion

DR. RIOCH: Mr. Eckert mentioned the problem of complexity in getting enough units into a computer. The whale has a brain several times larger than a man's, but the whale is not considered to be as intelligent. Here, the number of units is not the important thing.

MR. ECKERT: I'm sure you know two people who have the same size brains but are not equally capable. One of them is not "programmed" as well as the other. A computer and a brain seem to be different qualitatively and quantitatively. Thus, we must appreciate both these problems.

DR. RIOCH: Dr. Samuel, would you develop playing games more completely? I understand you had two machines that played checkers with each other.

DR. SAMUEL: I have succeeded in getting a computer to play checkers and, with time, to improve its playing. The program is good enough to beat most amateur checker players—and it has won a game against a professional. This was the first game he'd lost in eight years.

This program does not generate concepts. I had to give the computer the concepts. It exploits and explores them in future depth many times further than the human can do normally. The computer substitutes its tremendous speed

Compact FM Subcarrier Discriminators from Genisco Instruments

SMALLEST, LIGHTEST, LOWEST COST ON THE MARKET!

MODEL GSD-127
38 pound bandswitching Discriminator

A twenty-three I.R.I.G. channel discriminator for use where linearity, minimum distortion, and modular construction are of prime importance. Frequency Deviation: ±7.5% or ±15%; by special order any deviation from ±5% to ±40%. Input Dynamic Range: 25mv to 10V RMS. Output: ±10V @ 100MA.

MODEL 136C
3.5 pound Discriminator

Modular construction permits this subcarrier to be used on any I.R.I.G., or other, channel. Output: ±2.5V at 10 mils. Output Noise and Ripple: 6mv peak max. Linearity: ±0.1%. Frequency Deviation: Standard I.R.I.G. ±7.5% or ±15%. Nine A-136C Discriminators may be mounted horizontally in a standard 5-1/4" rack. Available in constant bandwidth models.

MODEL A-137
3.5 pound wide-band Discriminator

Like the Model 136C, this discriminator is only 4.375" high x 1.8125" wide x 14.0" deep. Its single difference is in an expanded band width in any deviation up to ±40% plus increased gain to be capable of operating directly off a tape recorder playback head.

MODEL 135
0.75 pound miniaturized Discriminator

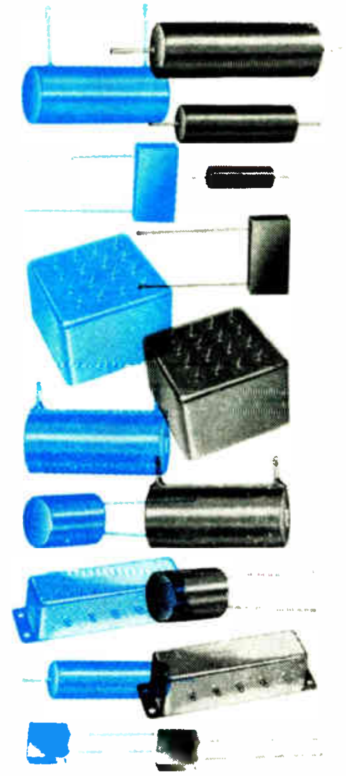
This tiny discriminator resolves weight and space problems and yet provides accurate acquisition of FM signal information at low cost. Frequency Deviation: ±7.5% or ±15%. Output: ±2.5V into 600 ohm load. Linearity: ±0.5% of bandwidth. Eighteen discriminators mount in 3-1/2" standard rack 16" deep.

No other discriminators in these price ranges offer the performance obtainable from these models.

For additional information and specifications, write for data file IS-2441-1.

Genisco Instruments

9036 Winnetka Ave., Northridge, Calif. Telephone: 341-4320 *a division of* Genisco INCORPORATED



PRECISION RESISTORS WITH PLUS FACTORS

+ Precision Tolerance, Down to ±.002%
+ High Reliability
+ Long Term Stability
+ Military and Higher Environments
+ Broad Product Line Exceeding MIL-R-93C

Carefully controlled manufacturing procedures and continuous attention to quality control insure resistors of matchless quality and reliability.

Typical controls include: Tension-free windings • Temperature cycling • Spot-welded terminations and • Epoxy vacuum impregnation.

Aging and drift are minimized in Genistron resistors to insure excellent long term stability.

Resistors and/or networks as well as RCL combinations are available. These are hermetically sealed or epoxy encapsulated for extreme environmental conditions.

Contact Genistron's Application Engineering Dept., or for complete information write for data file IS-2409-1.

Genistron INCORPORATED

6320 West Arizona Circle, Los Angeles 45, Calif. • SP 6-1411
111 Gateway Road, Bensenville, Illinois • Phone: 766-6550

subsidiary of Genisco INCORPORATED

and accuracy for people's "gestalt" ability. As a result, it plays a mediocre game of checkers.

DR. RIOCH: Dr. Kock, is there available data comparing the diagnostic ability of computers and doctors?

DR. KOCK: In the memory situation, the doctor's experience is so important that one must have always on file a huge store of memory and experience for the computer diagnosing any illness. How to retrieve this memory and diagnostic ability without such a quick access or large memory storage is still the problem.

DR. RIOCH: What is the future development of computer software likely to be?

DR. ZACHERY: The situation of computer software is dissimilar in many respects to that of computer hardware. Whatever the future development in hardware, it is almost certain that most engineering companies will be reasonably current with the state of the art. The same cannot be said of software. One of the major developments which could take place in the software field is to raise the levels of performance of major computer users to that which is already well known and well reported. Instead, many organizations using the computer appear intent on duplicating the errors which have been made more or less continuously in this field for the past 10 years. As an illustration, one needs merely to pick up an accounting article in order to encounter a heading such as: "How We Converted Our Payroll to a Computer," despite the fact that this type of operation has been known for a decade. I think we need more people who are able not only to compute answers to immediate problems but also who are willing to contemplate longer periods of time and the significance of the presently developing techniques for our way of life.

DR. RIOCH: Let me conclude this discussion with the observation that we don't spend enough time in the human mind in deciding upon the things we should really think about. We tend to take the current popular bandwagon, even if it may be heading for disaster.

New Fellow awards announced by IEEE Board of Directors

One hundred and eighteen leading IEEE members from the United States and six other countries were named Fellows of the IEEE by the Board of Directors at its meeting on October 30, 1963, in Chicago. The grade of Fellow is the highest membership grade offered by the IEEE and is bestowed on those who have made outstanding contributions to electrical engineering, electronics, and allied branches of engineering and science.

Presentation of the awards will be made by local Sections. Recognition of the awards will be made by the President of the IEEE at the Annual Banquet on March 25, 1964, at the New York Hilton Hotel during the 1964 International Convention.

The recipients of the Fellow award and their citations are as follows:

George Abraham
For research on solid-state phenomena and for contributions to graduate engineering education

J. T. Bangert
For contributions to the advancement of network design through the use of computers

R. A. Baudry
For contributions to the mechanical development and design of large rotating machines

R. C. Benoit, Jr.
For contributions in the field of military electronics

R. B. Blackman
For contributions to circuit theory and data processing

F. H. Blecher
For contributions to the design of solid-state circuits and their application to communication systems

J. P. Blewett
For contributions in the field of high-energy particle accelerators

Nicolaas Bloembergen
For fundamental contributions to masers and lasers

L. R. Bloom
For contributions to the development and design of microwave and millimeter-wave tubes

R. H. Bolt
For contributions to the field of acoustics through research and teaching

Nathaniel Braverman
For contributions to planning, development, and application of air navigation systems and techniques

G. M. Brunzell
For outstanding engineering proficiency, leadership, and administrative attainments

J. C. Cacheris
For contributions to advancement of microwave technology, particularly in the application of microwave ferrites

J. H. Chapman
For leadership in space research and scientific achievement in upper atmospheric radio physics

A. A. Cohen
For pioneering achievement on computers and storage devices and sustained service to the profession in this field

G. C. Dacey
For contributions in the field of solid-state devices and in research management

C. A. Desoer
For contributions to control theory, circuit theory, and engineering education

W. L. Doxey
For leadership in research and development of electronic materials and devices

H. W. Dudley
For contributions to the fields of speech theory, speech signal processing, and speech synthesis

A. J. Eaves
For pioneering developments of telegraph transmission systems, radio transmitters, and sound amplifying systems

K. R. Eldredge
For contributions to pattern recognition and magnetic character reading systems

R. G. Elliott
For contributions to communications services and as an engineering manager

Herbert Estrada
For contributions to the design and operation of interconnected power generating stations and systems

W. E. Evans, Jr.
For contributions to applications of video techniques and video systems

R. L. Frank
For contributions to radio navigation and the development of instrumentation for the Loran-C System

K. J. Germeshausen
For contributions to the technology of gaseous discharge flash lamps and stroboscopic lighting equipment

R. P. Gifford
For leadership in communications techniques and practice

G. M. Glasford
For contributions to engineering education and leadership in engineering activities

Janusz Groszkowski
For contributions in the field of frequency stability and electronic technology, and leadership in engineering education and research

E. W. Guernsey
For contributions to generation, transmission, and distribution of electric power

F. A. Gunther
For contributions to the fields of UHF and VHF communication and leadership in communications practice

F. E. Hanson
For contributions to manufacturing, engineering, and administration in the field of electron devices

E. O. Hartig
For contributions to the field of coherent high-resolution radar

O. C. Haycock
For contributions to research on the upper atmosphere and to engineering education

W. H. Hayt, Jr.
For contributions to electrical engineering education

G. E. Heberlein
For creative leadership in the switchgear field

Frank Herman
For contributions in the field of the energy band structure of solids

E. A. Hobart
For contributions in the fields of battery charging and welding

D. B. Holmes
For contributions to electronic early warning systems and leadership of manned space flight programs

R. R. Hough
For leadership in military electronics development associated with guided missiles

E. D. Huntley
For contributions to the design of large turbine generators

D. L. Jaffe
For contributions to the development of microwave electronic equipment

J. L. Jatlow
For contributions in the fields of FM carrier telegraphy and tropospheric scatter communication systems

P. H. Jeynes

automatic controls, electron devices, semiconductor circuitry, circuit theory, high speed data by wire, advances in telephone techniques, military electronics, satellite relays, communications systems, medical electronics, nuclear reactor instrumentation, audio, data processing, pattern recognition.

Abstracts of approximately 200 words are to be submitted by January 15, 1964, to the Technical Program chairman, Prof. Clayton Clark, Electrical Engineering Dept., Utah State University, Logan, Utah.

Conference scheduled on broadcast and TV receivers

The 1964 Chicago Spring Conference will be held at the O'Hare Inn, Des Plaines, Ill., on June 15–16. Papers are sought that would be contributions of significant interest to the home entertainment radio and television industry. Special consideration will be given to papers dealing with new concepts or new techniques associated with new or improved product design.

The deadline for receipt of papers is February 17. Potential authors are asked to submit, in triplicate, a summary of 50 to 100 words, including paper title, author(s), company affiliation, and position. Papers should be limited to 2500 words, and presentation to 20 minutes.

Papers should be submitted to F. H. Hilbert, Papers Committee, Motorola Inc., 9401 W. Grand Ave., Franklin Park, Ill.

Special issue of PROCEEDINGS on microelectronics planned

A forthcoming special issue of the PROCEEDINGS OF THE IEEE will be devoted to the field of microelectronics (integrated electronics) and is planned for the late Fall of 1964. Outstanding papers covering the state of the art and the most significant recent contributions in the field of microelectronics are sought for this special publication.

Papers pertaining to the following categories are requested:

1. Survey papers on broad, major aspects of microelectronics (e.g., economics; major technologies; philosophy of application; history; etc.)

2. Original papers on:

a. Microelectronic devices and structures (e.g., semiconductor structures; thin-film resistive, capacitive, magnetic, etc., structures; optoelectronic structures; etc.)

b. Materials, processes and techniques (e.g., substrates; deposition; photography; process control; etc.)

c. Interconnections and packaging

d. Circuit concepts and techniques using microelectronic structures (digital, linear; trade-offs; isolation, coupling; margins; frequency; power)

e. System aspects (e.g., trade-offs, system design using microelectronic devices; etc.)

f. Concepts, design, and performance of electronic equipments using microelectronic devices (military and industrial)

g. Reliability of microelectronic devices and equipments

h. Special topics (e.g., compatibility, hybrid structures and systems, etc.)

Two kinds of papers will be considered for publication:

1. Contributions of reasonably broad impact described in full length papers.

2. Contributions of limited impact described in brief monographs not exceeding 2000 words (corresponding approximately to two pages of the PROCEEDINGS). Expanded versions of such monographs can be recommended for publication in the TRANSACTIONS of appropriate Professional Technical Groups.

To facilitate the organization of the special issue, prospective authors are requested to inform the undersigned at their earliest convenience of their intent to submit a paper, indicating the subject and probable length of their contributions. Complete manuscripts should be submitted as soon as they are available. The tentative deadline for receipt of complete manuscripts is May 15, 1964. A small extension of time may be granted for work in progress if a suitable detailed abstract is received.

Three copies of each paper and of all illustrations pertaining to the paper should be submitted to: A. P. Stern, Editor, Microelectronics Issue of Proceedings of the IEEE, Martin Co., Electronic Systems & Products Div., Baltimore, Md. 21203. Attn: Mail No. 3031. The submission should include one original typed copy with one set of reproducible illustrations. A photograph and a biography of the author should be attached.

Further inquiry may also be directed to E. K. Gannett, Managing Editor, Proceedings of the IEEE, Box A, Lenox Hill Station, New York 21, N.Y.

Some customers really challenge us

Take the case of the commercial airlines. They needed a transducer that would accurately measure jet engine vibration in flight—yet would not disintegrate from the vibration as well as the searing heat.

Since CEC had pioneered and perfected vibration transducers for reciprocating engines, we believed we could do the same for jets. Result: CEC's first models successfully passed every ground and laboratory test. But when they took to the air it was another story. Failure followed failure. The airlines began to wonder if the answer *could* be found. And so did we.

That was six years and hundreds of experiments ago. Today the engine nacelles of increasing numbers of jet airliners carry pairs of tiny CEC 4-125 Vibration Transducers. Some of these 4-125s have already logged more than 3,600 hours—*all* are still functioning—and that's a record no other manufacturer has approached.

This is another case in point why CEC's leadership in the development and production of all phases of data recording has been advanced by troublemakers we're proud to call customers.

And it's why CEC has established a network of 22 sales and service offices throughout the nation. To expedite application engineering. To help train customer personnel in the use of advanced instrumentation. To find positive answers to evasive problems.

CEC

CONSOLIDATED ELECTRODYNAMICS

BELL & HOWELL/

Spectral lines

Greetings! With the birth of IEEE SPECTRUM comes the opportunity through this page, appropriately entitled "Spectral Lines," for the Editor to speak each month to the membership. It is the intent of the Editorial Board that our new journal provide as much personal contact as possible with the members, that it bring news of the organization and of the profession, and that it encourage education in the basic areas as well as in the results of recent research. Thus some of its "news" may actually be found in its editorial content rather than in its departments.

While limited in space, it is proposed that this page provide the Editor with an opportunity to also provide such personal contact. It is hoped that the topics discussed here will encompass a spectrum as broad as the IEEE technical interests, and as diverse as is the spectrum of membership functions. Your comments on matters discussed here will always be appreciated, and when appropriate may appear as letters in the "Correspond-[illegible]e" section.

Chicago and NEC. The National Electronics Conference, a yearly Chicago function since 1944, this year also included many activities and much program that might have been associated with the former AIEE Fall Meeting. Upon invitation the Board of Directors held its fourth meeting of the year at the NEC, and also met informally with the officers of NEC, attended a Chicago Section meeting, and heard Dean W. L. Everitt address an NEC luncheon on problems in continued education.

The Board received reports from its Awards Board concerning those to be honored at events in the next year, discussed continuing problems arising from Section and Region merger, and heard from the IEEE Treasurer of the efforts to contain the expected and occurring first-year-of-merger deficit. Other items included a discussion of plans to acquire a new computer for processing of membership and financial data, accounting, and other data-processing functions. It is expected that the computer will be available to the other professional organizations housed in the United Engineering Center, as well as performing an indispensable service for our headquarters.

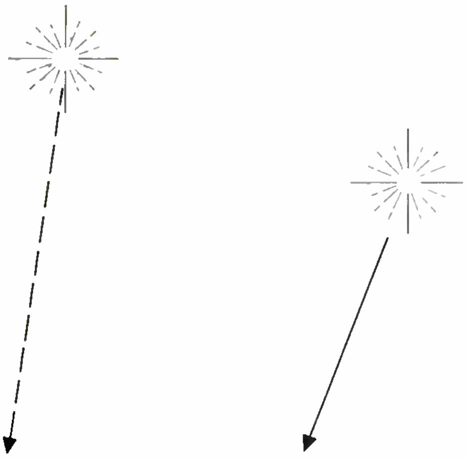
In general, the Regional Directors reported completion of merger at the Section level, and that those organi-[illegible]ons were now functioning at high efficiency. Some [illegible]ncern was reported from the Student Branch area, where it was felt that in several Regions the merger activity had not advanced the program. Further action can be expected along this line, especially as several Regions develop more complete cooperation with their Regional Education Committees and other groups within the Region.

News of the formation of the Professional Technical Group on Power, and of the merger of several Professional Technical Groups and appropriate Technical Committees was greeted warmly. With the approval previously given to standards activities by the PTG's, it now seems to us that a PTG organization has all the opportunity formerly given to a Technical Committee, plus a closer association with an identified group of the membership, plus greater opportunity to serve that membership through directed programs and symposia, including exhibits, plus greater freedom in serving this membership through selective publication. We hope for continued study of the problems of duplication of effort existing in our organization, and for broad and impersonal thinking which will always emphasize the question "How best do we serve the needs of the *membership?*"

The Board also discussed the position of the Institute in intersociety relations, particularly with respect to member interests in professional, legal, and civic areas. Clearly, from this discussion, the Board believes that IEEE, because of its great diversity in interest and viewpoint, cannot accept responsibility for representing the opinions of individual members on such professional topics; it was suggested that when members desire such representation they consult other organizations.

The second day of the Board of Directors meeting at Chicago was reserved for further discussion of editorial policy. Looking to this, the Editorial Board had spent many hours on the preparation of a statement of editorial objectives, additive to the proposal adopted in June 1963, which led to the establishment of IEEE SPECTRUM. After considerable discussion in Committee of the Whole, the Board adopted a slightly modified version of the Editorial Board proposal. The statement defines the IEEE publication objectives as two-pronged—to provide for rapid dissemination of research results important to our field, and to furnish a means for furthering the education and technical abilities of our members. The Editorial Board will have coordinating powers over all of our publications, in order to ensure that basic policies are carried out, and to determine that appropriate standards are being maintained. It is hoped that a more detailed report of the genesis of our editorial policies can be presented in an early issue of this journal.

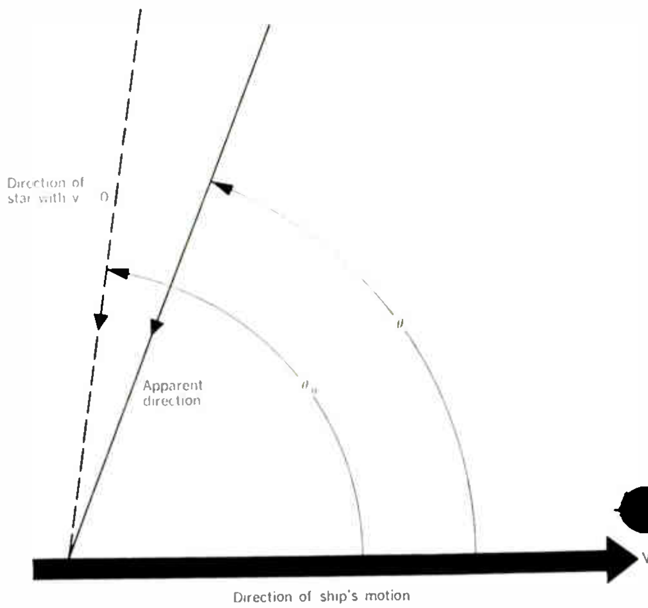
J. D. Ryder



The view from the starship bridge and other observations

A theoretical journey into space three light years from earth and back brings into play several interesting concepts, including optical Doppler shift and aberration, relativity, and time dilation

B. M. Oliver — *Hewlett-Packard Company*



In alluding to the appearance of the sky as seen from a fast-moving spaceship, writers of science fiction (and scientific fact) often mention the reddening of stars astern and the bluing of those ahead. Occasionally tribute is paid to Lorenz and Fitzgerald and, as the ship approaches optic velocity, the universe is described as foreshortened in the direction of motion. The color changes are quite correct, but no one who had stood on the bridge of a fast starship would ever make the second statement. The changes in appearance are completely described by relativistic Doppler and by relativistic aberration, both first-order effects in v/c, where v is the velocity of the ship relative to the source and c is the velocity of light.

Nonrelativistic Doppler is familiar to all of us in the form of the increased pitch of the approaching whistle or siren and the drop in pitch as it passes. Nonrelativistic aberration can be observed in a calm rain. If we stand still the drops appear to fall vertically, but if we run in any direction the drops appear to come from that direction. If we want them to fall straight down a tube we must tip the tube forward. So it is with photons and telescopes. In 1727, Bradley noticed that the stars as a group, particularly those near the normal to the ecliptic, execute an annual circular motion—the displacement of the star from its mean position being in the direction of the earth's orbital motion.

The exact expressions for optical Doppler shift and aberration can be computed from the theory of relativity.[1] The Doppler shift is given by

$$\frac{\nu}{\nu_0} = \frac{\sqrt{1-v^2/c^2}}{1-(v/c)\cos\theta} \qquad (1)$$

And the aberration by

$$\tan\theta = \frac{\sqrt{1-v^2/c^2}\,\sin\theta_0}{\cos\theta_0 + v/c} \qquad (2)$$

where

ν = observed frequency of light

θ = apparent angle of source with respect to ship's velocity vector (heading)

and the subscript zero indicates the quantity as observed with $v = 0$.

For sources dead ahead $\theta = 0$, and (1) gives

$$\frac{\nu}{\nu_0} = \sqrt{\frac{1+v/c}{1-v/c}}$$

while for those dead astern $\theta = \pi$ and

$$\frac{\nu}{\nu_0} = \sqrt{\frac{1-v/c}{1+v/c}}$$

For sources (apparently) directly to the side, $\theta = \pi/2$ and

Fig. 1 (left). The aberration of light. The motion of an observer relative to a source causes the apparent direction of the source to shift forward. Because it is a first-order effect in v/c, aberration is detectable at moderate velocities such as that of the earth in its orbit

$$\frac{\nu}{\nu_0} = \sqrt{1-\frac{v^2}{c^2}}$$

This last expression is the so-called transverse Doppler effect and shows the retardation of moving clocks.

Turning to Eq. (2) we see that for $v > 0$, $\theta < \theta_0$ unless $\theta_0 = 0, \pi$. All sources appear to be swept forward as shown in Fig. 1, except for any already directly ahead or directly astern. The universe appears to redden and thin out to the stern and to become bluer and denser ahead. As $v/c \rightarrow 1$, the entire universe, save for the stern point, appears to concentrate in front of the ship.

Either by going through the algebra, or by noting that we may interchange θ and θ_0 provided we reverse the sign of v, we may rewrite (2) as

$$\tan\theta_0 = \frac{\sqrt{1-v^2/c^2}\,\sin\theta}{\cos\theta - v/c} \qquad (3)$$

or (since, if $\tan x = a/b$, $\sin x = a/\sqrt{a^2+b^2}$ as

$$\frac{\sin\theta_0}{\sin\theta} = \frac{\sqrt{1-v^2/c^2}}{1-(v/c)\cos\theta} \qquad (4)$$

Finally, we can differentiate (3) to obtain

$$\frac{d\theta_0}{d\theta} = \frac{\sqrt{1-v^2/c^2}}{1-(v/c)\cos\theta} \qquad (5)$$

Comparing (1), (4), and (5) we note that the right sides are identical—a fact of some significance, as we hope to show.

All sources that lie within the angular annulus of width $d\theta_0$ are shifted forward and lie within the annulus of width $d\theta$, as shown in Fig. 2. Thus the size of objects in the θ direction changes by the factor $d\theta/d\theta_0$. Since the circumference of the annulus changes by the factor $\sin\theta/\sin\theta_0$, distances measured along the circumference change by the same factor. Small constellations will thus appear unchanged in shape. Finally, since $\lambda = c/\nu$, we may take (1) to be a measure of λ_0/λ or dr_0/dr, so radial distances appear to change by the same factor. To sum up,

$$\frac{dr}{dr_0} = \frac{r}{r_0} = \frac{d\theta}{d\theta_0} = \frac{\sin\theta\,d\phi}{\sin\theta_0\,d\phi} = \frac{1-(v/c)\cos\theta}{\sqrt{1-v^2/c^2}} \qquad (6)$$

which says that all *apparent* dimensions of small solid objects change by the same ratio, and thus their apparent shape is unchanged. By more elegant methods it has been shown[2] that a sphere of any apparent size remains spherical.

We stress the word "apparent" because computation would show the radial and lateral dimensions to have changed differently; that is,

$$\frac{r\,d\theta}{r_0\,d\theta_0} = \frac{r\sin\theta\,d\phi}{r_0\sin\theta_0\,d\phi} = \left(\frac{dr}{dr_0}\right)^2 \qquad (7)$$

When we are viewing stars, it is convenient to speak of densities. These vary inversely with size and hence the factors are given directly by (1), (4), or (5). The apparent linear density is the original density times $f(\theta)$, where

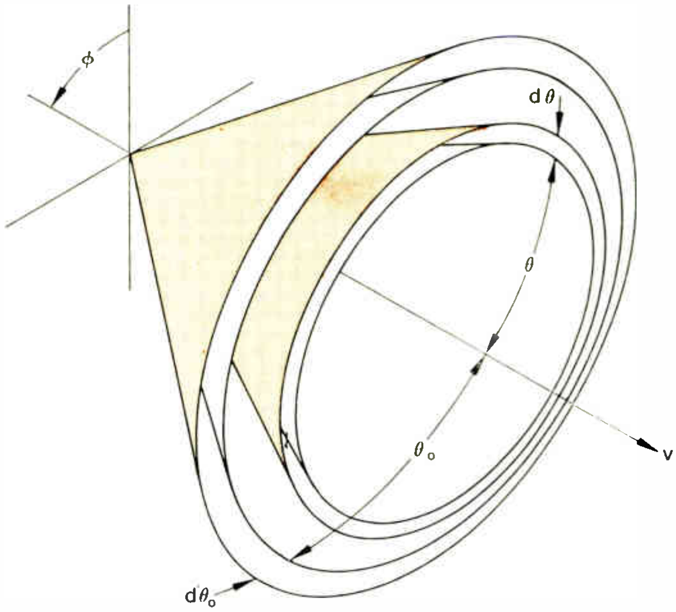


Fig. 2. Conformal mapping property of aberration. Stars lying between the cones θ_0 and $\theta_0 + d\theta_0$ with the ship at rest appear to lie between the cones θ and $\theta + d\theta$ when the ship is in motion. Circumference of annulus is proportional to sin θ. Transformation is such that $d\theta/d\theta_0 = \sin\theta/\sin\theta_0$, so compression is equal in the θ and ϕ directions

$$f(\theta) = \frac{\sqrt{1 - v^2/c^2}}{1 - (v/c)\cos\theta} \tag{8}$$

This is the equation of a prolate spheroid with one focus at the origin and the other lying on the axis $\theta = 0$. Figure 3 shows a plot of (8) for $v/c = 0.6$. Directly ahead the densities are doubled; directly to the rear they are halved.

To verify our interpretation of (1) as a measure of radial density let us consider a distance measurement made by a ship. Assume that a series of corner reflectors is distributed along a straight line in space at intervals of one light year and that a space ship is traveling along this line at a velocity 0.6c. In coordinates fixed with respect to the reflectors, the trajectory of the ship, which moves three light years to the right in five years' time, is shown by the heavy line *OMP* in Fig. 4. Since the reflectors move in coordinate time but not coordinate space, their trajectories are vertical lines. Events on the line *OMP* are seen by the ship at the same place (the ship) but at different times, so the trajectory *OMP* is the ship's time axis. According to relativity theory the ship's clock runs at $\sqrt{1 - (0.6)^2}$, or 0.8 the rate of the coordinate clocks, and therefore it records four years in five coordinate years, and the trajectory is so marked. Let us call the coordinate time t and ship's time t'. At $t = t' = 0$, the ship is at O and sends out a light pulse, which propagates along the 45-degree dashed lines at one light year per year.

After $t = 2$ years (at S) the reflections from reflectors R_{-1} and R_1 return to the point of origin in the coordinate system. They are received simultaneously and the

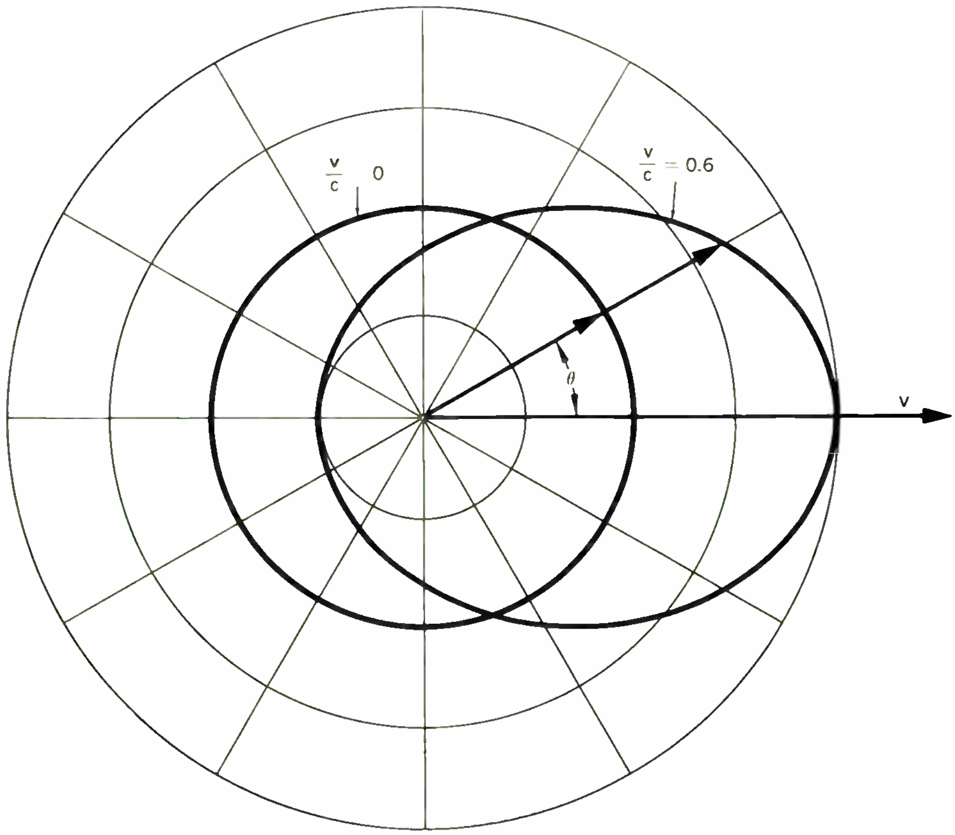


Fig. 3. Effect of velocity on apparent density. If the sky were uniformly besprinkled with stars the apparent density with the ship at rest plots as a sphere; that is, the radius (proportional to density) is independent of direction. With the ship in motion this plot becomes a prolate spheroid with the ship at one focus. Angular and radial densities change by the same factor f(θ), increasing ahead and decreasing astern

Fig. 4 (right). Radar measurement of densities. Corner reflectors are strewn along a line at intervals of one light year. A ship moving along this line with v = 0.6c sends out a radar pulse at O. The ship gets a return every year from those ahead, indicating a one-half light-year spacing; and every four years from those astern, indicating a two light-year spacing. These are the apparent densities predicted by f(θ). Here and in Fig. 5 the items in color pertain to the ship's frame of reference, rather than the earth's operator there is gratified to learn that R_{-1} and R_1 are each a light year away; or rather that they *were* at that time $t = 1$ when he assumes the reflection took place —as indeed it did, in *his* time.

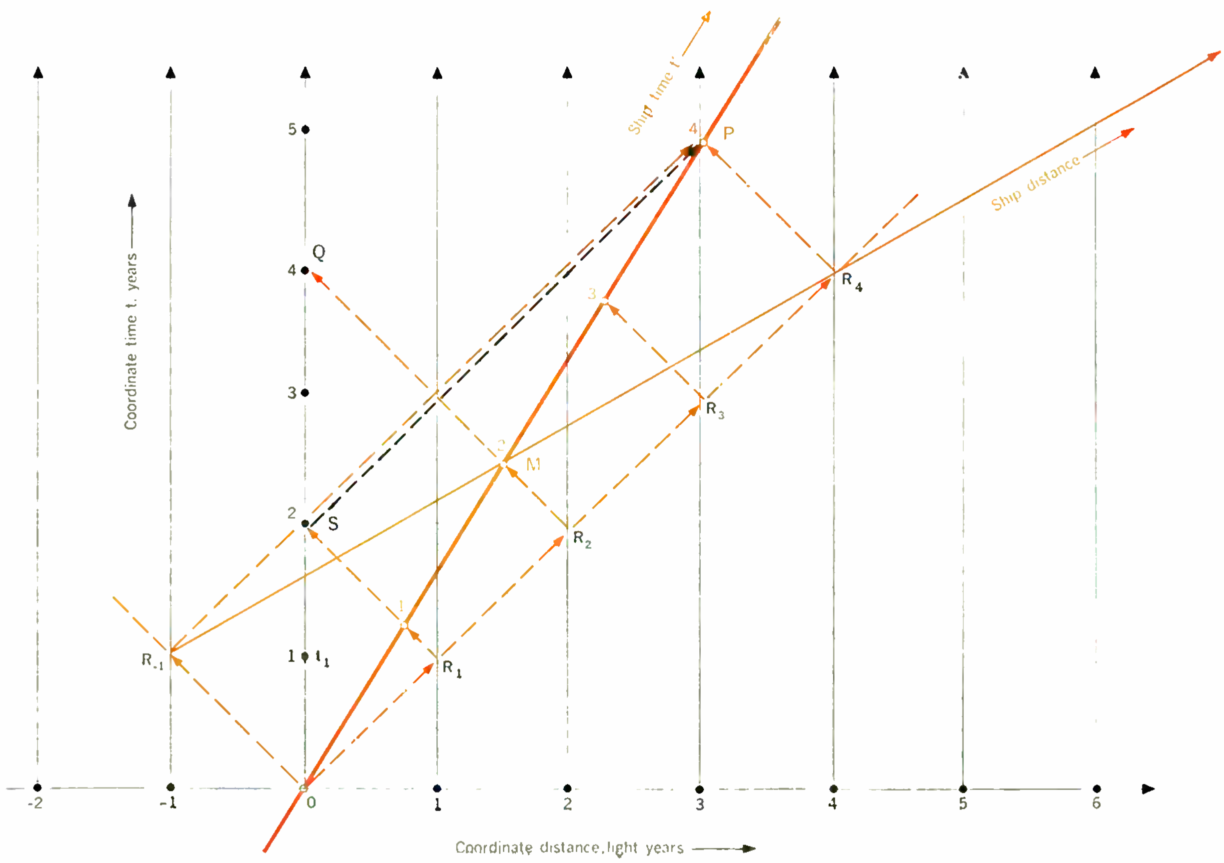
After four years of ship's time the reflections from R_{-1} and R_4 are received simultaneously by the ship. The ship's operator therefore concludes that R_{-1} and R_1 were both two light years from him at M, or the time $t' = 2$ when *he* assumes the reflections took place. In effect he measures distance parallel to the dashed line $R_{-1}R_1$, which he calls four light years long. Events on any line parallel to $R_{-1}R_4$ he calls simultaneous.

Notice that from the reflectors that were ahead of him at $t' = 0$, he receives an echo every year and he concludes that they are one-half light year apart. Also, since it takes four years per echo from those astern, he concludes that their spacing is two light years. His measurements, which show twice the density in front and one half the density behind (as compared with the coordinate observer), are in complete accord with (1) and (8).

A pulse emitted by the ship after two years of ship time is received by the coordinate observer after four years of coordinate time, as shown by the line MQ. Similarly, a pulse emitted by the coordinate observer after two years of coordinate time is received after four years of ship time as shown by the line SP. Thus both observers receive half frequency from the other as required by (1). This symmetry would not exist if we had assumed five years' ship time between O and P rather than four.

As long as we are on the subject we may as well discuss the clock paradox. This is *not* the fact that the twin who has taken the journey ends up the younger, though this seems strange to many people. Rather it is a logical impasse that arises in the following example. Two clocks, one in a spaceship, the other in an internal frame, are synchronized. The spaceship then makes its trip to a distant point and returns. It is then incorrectly argued that "since each sees the other's clock running slow while the relative motion exists (which, in the limit, is all the time), each clock will be ahead of the other when the ship returns"—clearly an impossibility. The student concludes that either he is out of his mind (which is distressing) or Einstein was (which is irreverent, but less distressing). In this way much skepticism of relativity develops. To see what really happens all we need to do is draw a diagram like Fig. 4 (a Minkowski diagram) for the entire trip. This we have done in Fig. 5.

The ship, at $v = 0.6c$, takes five earth years to travel to a point three light years away and five more earth years to return. Each year, by their own clocks, earth and ship send each other a light pulse, as shown by the 45-degree dotted lines, so $\nu_0 = 1$ pulse per year. During the time either thinks the other is receding, the received frequency of pulses is $\nu_0/2$, as required by (1); and when either thinks the other is approaching, the received frequency is $2\nu_0$, again as required by (1). But the ship realizes it is returning as soon as it accelerates at $t' = 4$ years. Earth, on the other hand, has to wait for a light signal to communicate this fact at $t = 8$ years. So the earth receives the lower frequency for a longer time, and gets fewer total pulses from the ship than the ship gets



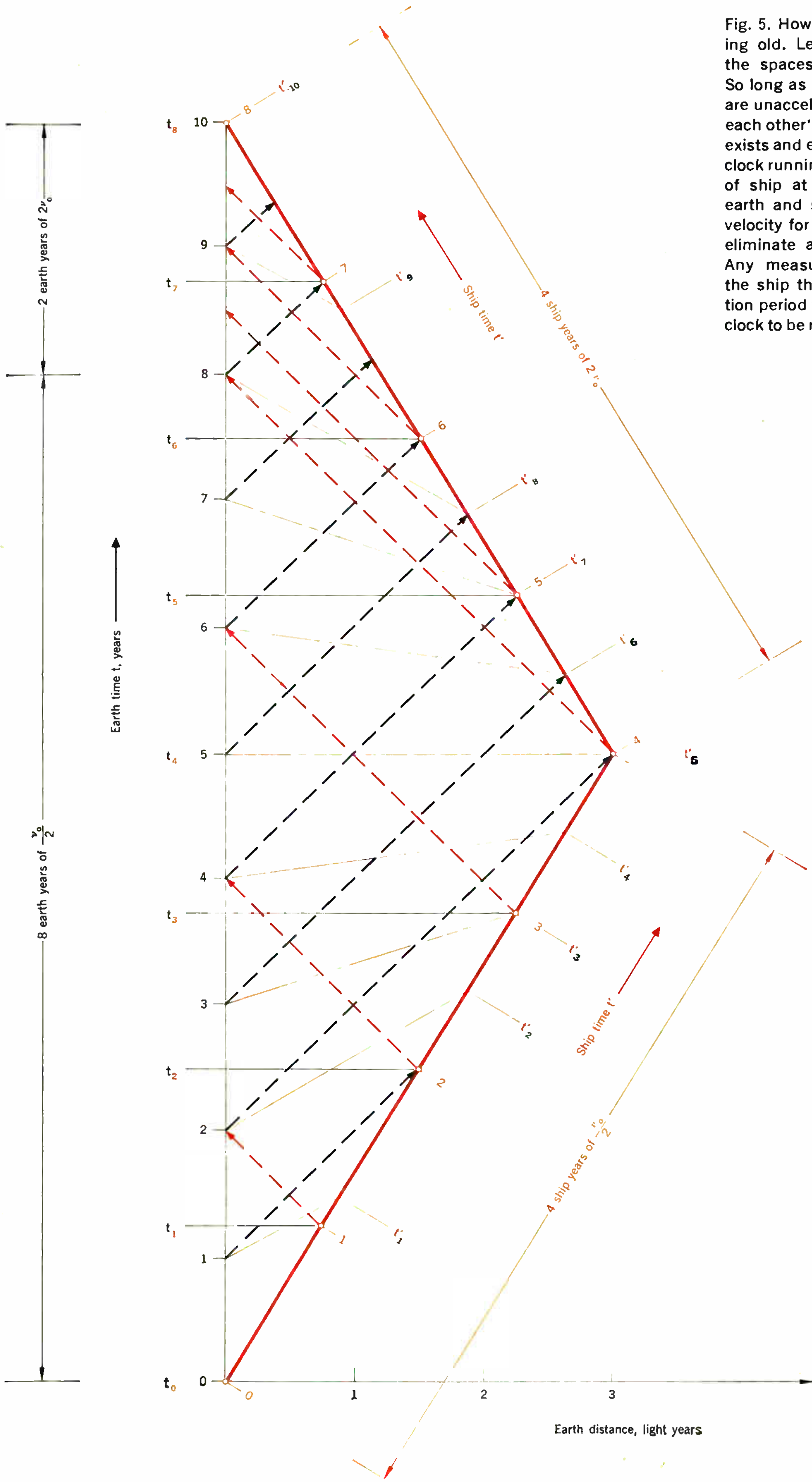


Fig. 5. How to keep from growing old. Less time elapses in the spaceship than on earth. So long as both earth and ship are unaccelerated and agree on each other's velocity, symmetry exists and each sees the other's clock running slow. Acceleration of ship at destination causes earth and ship to disagree on velocity for just long enough to eliminate any logical paradox. Any measurements made by the ship that include acceleration period will show the earth's clock to be racing ahead

from the earth. Thus, even though symmetry exists while each thinks the other has the same velocity, earth and ship disagree on the relative velocity long enough to eliminate any paradox.

To estimate the other's clock rate, correction must be made for propagation times. Thus the earth can consider the pulse received at $t = 4$ years to be a radar return of the one sent at $t = 1$. Reasoning that the light took the same time to go and return, the earth concludes that the reflection (or the transmission) from the ship took place at $t_2 = (1 + 4)/2 = 2.5$ years. But, being the second one received, the pulse must have been sent at $t' = 2$ years. Earth thus concludes the ship's clock is running at

$$\frac{t'}{t} = \frac{2}{2.5} = 0.8 = \sqrt{1 - \frac{v^2}{c^2}}$$

times earth rate. In the same way the times $t_1 \ldots t_{10}$ may be determined and all show the ship's clock to be running at the same slow rate; that is, $dt'/dt = 0.8$. Note that simultaneous events in the earth's frame always lie on horizontal lines.

In exactly the same way the ship regards the signal received at $t' = 4$ to be a radar return of the one sent by the ship at $t' = 1$ and concludes it was reflected (or sent by earth) at $t' = 2.5$. Again it is the second pulse received, so it was sent at $t = 2$ years. Thus up to this point the ship also sees the earth's clock running at 0.8 ship's rate. The situation is symmetrical, as required by special relativity, because up to this point both frames have been inertial—that is, unaccelerated. As soon as the ship accelerates (at $t' = 4$), interpreting each received signal as a radar return and splitting the time between ship's transmission and reception to find the time of earth reflection yield the times $t_3' \ldots t_8'$. During this period, in retrospect, the earth's clock appears to have been running at twice ship rate. Finally from t_8' to t_{10}', with the acceleration period excluded once more, the earth's clock (now ahead) appears to revert to 0.8 of ship rate. Thus the average rate is

$$\frac{0.8 \times 2 \text{ years} + 2 \times 3 \text{ years} + 0.8 \times 2.5 \text{ years}}{8 \text{ years}} = 1.25$$

or the reciprocal of the ship clock rate as determined by earth. Note that simultaneous events in the ship's frame lie on sloping lines. The two clocks do not agree upon the ship's return, but this is no logical paradox. It is plain time dilation and is as real as (and no more mysterious than) $E = mc^2$, which most people believe today.

Using the Mossbauer effect,[3] one can detect the time dilation produced by modest velocities and gravitational potentials. Cobalt-57 decays to excited-state iron-57. The excited Fe^{57} then emits a photon (a 14.4-kv gamma ray) that can be absorbed and reradiated by other Fe^{57}

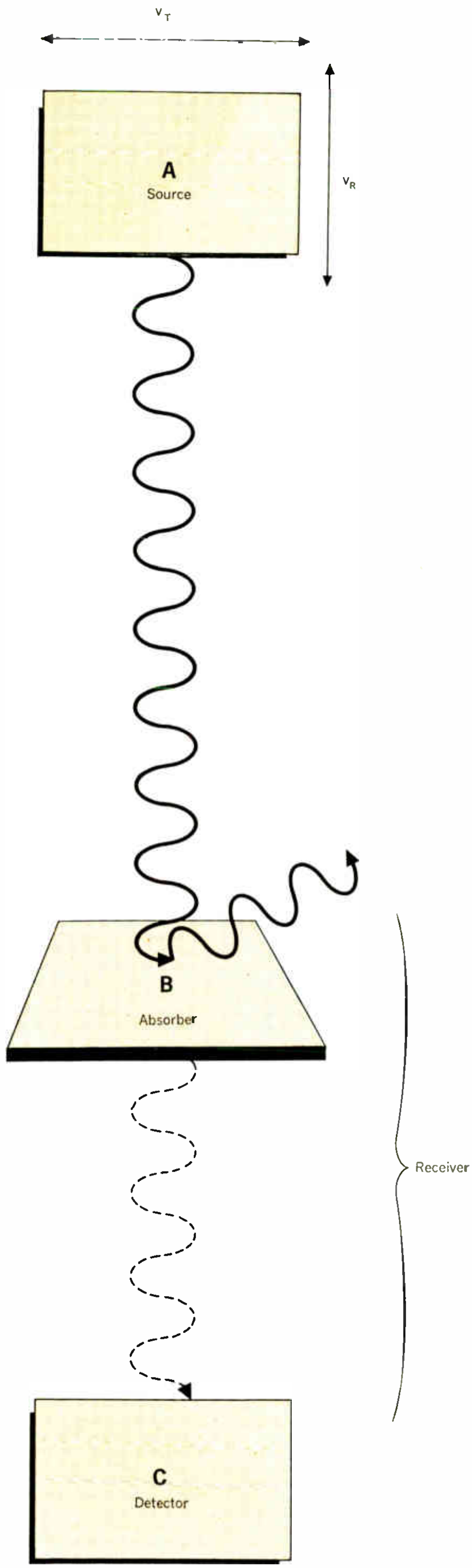


Fig. 6. Doppler detection using Mossbauer effect. Radioactive source A emits very monochromatic radiation. By absorption and re-emission highly resonant absorber B scatters radiation in all directions, thus shading detector C. The slightest frequency shift prevents scattering and increases the output of the detector

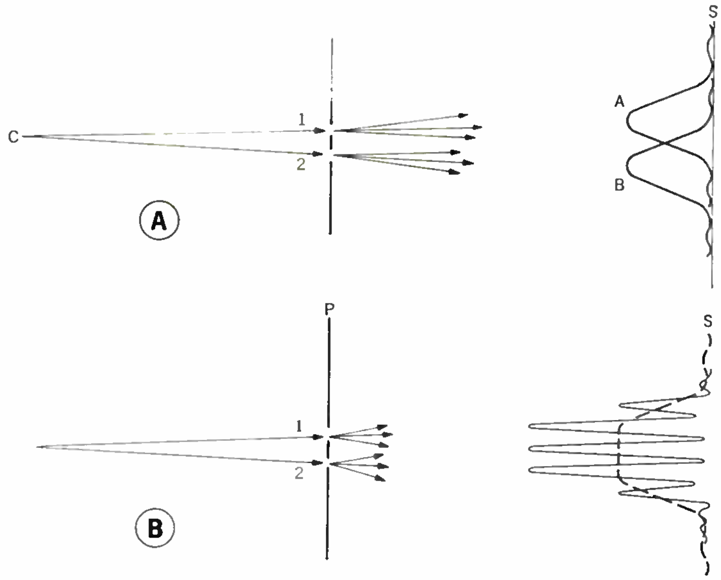


Fig. 7. Diffraction of electrons. Electrons from a cathode C pass through slits in a plate P. If only slit 1 is open, the distribution of arrivals on screen S is as shown by curve A in (A). If only slit 2 is open, distribution B results. If, with both slits open, electrons came only through one slit or the other, distribution would have to be sum of curves A and B as shown by the dashed curve in (B). Actual distribution shows interference maxima and minima. Thus both slits contribute to the arrival of each electron

nucleii. Thus the intensity at the detector in Fig. 6 is reduced by the absorber, which scatters the incident radiation in all directions. However, the radiation of the Fe^{57} source is extremely monochromatic and the absorber is extremely frequency selective; in fact the Q is about 1.6×10^{12}. This is like having an X-band receiver with a bandwidth of 1/160 c/s. As a result the absorption is extremely sensitive to frequency shifts. The Doppler shift caused by a radial velocity v_R of only one foot per hour will cause a significant decrease in scattering and so increase the detector flux. Likewise, a transverse velocity v_T of 800 feet per second produces a detectable relativistic transverse Doppler shift. The frequency emitted by the moving atoms drops. This frequency drop also occurs as the result of rms thermal velocity of the nucleii if the source is heated with respect to the absorber.

With a receiver 74 feet below the source, Pound and Rebka were able to measure the blue shift of the falling photons. Thus the atomic clocks at a higher gravitational potential appear to run fast.

All such measurements have been in agreement with the theory of relativity, which says that

$$\frac{d\tau}{dt} = \left(1 + \frac{2\chi}{c^2} - \frac{v^2}{c^2}\right)^{1/2}$$

where $d\tau$ is the increment of time measured by a clock at a gravitational potential χ and moving at a velocity v with respect to the coordinate clock, which measures dt. As the moving, elevated clock describes its trajectory, the total time dilation is

$$\Delta t = \int dt - \int d\tau = \int \left[1 - \left(1 + \frac{2\chi}{c^2} - \frac{v^2}{c^2}\right)^{1/2}\right] dt$$

For ordinary potentials and velocities such that

$$\frac{2\chi}{c^2} \text{ and } \frac{v^2}{c^2} \ll 1$$

$$\Delta t = \frac{1}{c^2}\int\left(\frac{v^2}{2} - \chi\right) dt = \frac{1}{mc^2}\int (T - V)dt$$

where

$T = \frac{1}{2} mv^2$ = kinetic energy of body

$V = m\chi$ = potential energy of body

The time dilation for a body executing a trajectory at nonrelativistic speeds and potentials is the integral of the Lagrangian $L = T - V$, divided by the rest energy, mc^2. In other words, *the difference in clock rates is proportional to the excess of kinetic energy over potential energy.*

Hamilton's principle of least action states that for a free body the path is such that $\int L\, dt$ is least (or takes an extreme value). From the foregoing we see that this is the same as requiring that the time dilation be least (or stationary), and represents the nonrelativistic approximation of the principle that, for a geodesic, $\int d\tau$ is an extremum.

We normally think of electrons as indivisible particles. Just as Young's experiment in optics established the wave nature of light, electron diffraction (Fig. 7) forces us to assign wave properties to matter. Some years ago Feynman[4] showed that, at least in the nonrelativistic case, the diffraction and interference of particles (for example, electrons) was consistent with the concept that all possible trajectories contributed equally to each arrival. To each possible trajectory is assigned a (complex) probability amplitude with a phase $\theta = (2\pi/h) \int L\, dt$. For each of the possible end points all probability amplitudes are added to give a complex number whose magnitude squared is the probability of detecting an arrival at that point. If a large number of paths contribute in nearly the same phase, the probability will be large. If the phases cause the amplitudes to cancel, the probability of arrival is zero.

From the foregoing we see that θ is the phase shift $2\pi f\Delta t$ that would occur in an oscillator of the Compton frequency $f = mc^2/h$ as a result of the time difference

$$\Delta t = \frac{1}{mc^2}\int L\, dt$$

Is time dilation, then, an intrinsic ingredient of all motion, determining it as much as being determined by it? Or have our fancies led us astray?

Perhaps it is time to turn our gaze back to the stars. They seem to be in their proper places once more, for we have come to the end of our flight. Does anyone feel younger?

REFERENCES

1. Møller, C., *The Theory of Relativity*. New York: Oxford University Press, 1952, p. 62.

2. Boas, M. L., "Apparent Shape of Large Objects at Relativistic Speeds," *Am. J. Phys.*, vol. 29, no. 5, May 1961, pp. 283–286.

3. Wertheim, G. K., "The Mossbauer Effect: A Tool for Science," *Nucleonics*, vol. 19, no. 1, Jan. 1961, pp. 52–57.

4. Feynman, R. P., "Space-Time Approach to Nonrelativistic Quantum Mechanics," *Revs. Modern Phys.*, vol. 20, no. 2, Apr. 1948, pp. 367–387.

High-power solid-state devices

Advances in process technology are giving rise to the appearance on the market of an increasingly large number and variety of economical high-power semiconductor devices

I. A. Lesk, C. B. Ackerman, W. E. Taylor, J. C. Haenichen, W. C. Davis, G. B. Finn *Motorola Semiconductor Products Division*

In any "state of the art" discussion, particularly when the field is as broad as that of solid-state devices, it is important at the outset to define the basic area to be covered. For the purpose of this article, solid-state devices will be restricted to those utilizing p-n junctions in single-crystal semiconductor material. From the standpoints of practical usefulness and availability, we are then further restricted to the consideration of silicon and germanium p-n junction devices, limiting our discussion to those capable of handling a high power. Other high-power solid-state devices—many of them utilizing a semiconductor material—include resistors, capacitors, transformers, thermoelectric generators, barrier-layer rectifiers, crystal lasers, piezoelectric and magnetostrictive transducers, photoresistors, positive thermal coefficient thermistors, and varistors.

What differentiates a high-power from a low-power device has not been universally established. Moreover, a power that is considered high at microwave frequencies may be relatively low in the audio range. In addition, the mode of operation, such as amplification (in various classes) or switching, makes a big difference in how much power the device handles. We shall use as an approximate definition of high-power devices those capable of dissipating more than one watt, and exhibiting useful characteristics under this condition.

High-power semiconductor p-n junction devices are large (active dimension generally in the range 0.05 to 1 inch) compared to signal devices (0.001 to 0.05 inch). Hence, they are still much more difficult to manufacture free from catastrophic defects than are low-power components. However, advances in process technology (including, for example, epitaxy, diffusion, crystal growing, alloying), along with a continually improving understanding of the physics of device operation and failure, are giving rise to the appearance on the market of an increasingly large number and variety of economical high-power semiconductor devices. The future should witness a continuation of this trend, so that five years from now most of the high-power semiconductor p-n junction devices on the market will be made of silicon, of the types described in this article, but extending to higher power ranges. A large number of germanium power alloy transistors will probably still be used, and perhaps power varactors using gallium arsenide will appear.

Basic power considerations

The power level to which a device can be driven depends upon operational, reliability, and thermal limitations. Operational limitations refer either to those that physically prevent the voltage or current level from exceeding a certain value, or reduce the efficiency of operation to a useless value even though higher voltages or currents could be achieved. Operational limitations are discussed separately for the case of each device.

Reliability limitations refer to changes that high temperature, voltage, and current (in various combinations) can cause in the characteristics of devices after long periods of application. The failure rate generally increases at higher powers, and can be a factor that limits the operating power level of a device for ultrareliable applications. Failures of this type are surface induced, and are the subject of intensive research at present. As reliability is increased, even better results will be obtainable at lower power levels. For most applications, the major power limitations are operational and thermal, so reliability limitations need not be discussed here further. It should be noted, however, that hermetically sealed packages are necessary for the present high level of reliability that is obtained (failure rates of ≈ 0.001 per cent per 1000 hours under operating conditions).

Thermal limitations are those that prevent operation of the device at a higher power level in a specified heat flow configuration, even though it could operate efficiently at higher power in a more efficient thermal environment. The more important thermal limitations common to all semiconductor devices are discussed in this section.

The *V-I* characteristics of a p-n junction are shown in idealized form in Fig. 1. In the forward direction (p-type region positive) the current increases in an exponential manner with voltage. On a linear scale, this closely resembles a region of very low resistance offset by a voltage V_F (about 1 volt for silicon, 0.5 volt for germanium) from the current axis. In the reverse direction, a very-high-resistance region limits current I_L to the approximate ranges of 1 nanoampere to 1 microampere for silicon and 1 microampere to 1 milliampere for germanium. This high-resistance region is abruptly terminated in a very-low-resistance region beginning at the avalanche breakdown voltage V_B.

Thermal limitations on the power level to which a p-n junction device may be operated are almost always caused by the extreme temperature sensitivity of the reverse leakage current I_L.

To a first approximation

$$I_L \propto e^{-qV_G/kT} \quad (1)$$

where

V_G = semiconductor band gap, about 1.1 volts for silicon and 0.7 volt for germanium at room temperature
T = temperature in °K
kT/q = 26 mV at 27°C (300°K)

The rate of change of I_L with temperature

$$\frac{dI_L}{dT} \approx \frac{qV_G}{kT^2} I_L \quad (2)$$

An approximation sufficiently accurate for many calculations over the normal range of operation of most silicon and germanium p-n junction devices (−50 to +150°C) is

$$\frac{dI_L}{dT} \approx 0.1 I_L \quad (3)$$

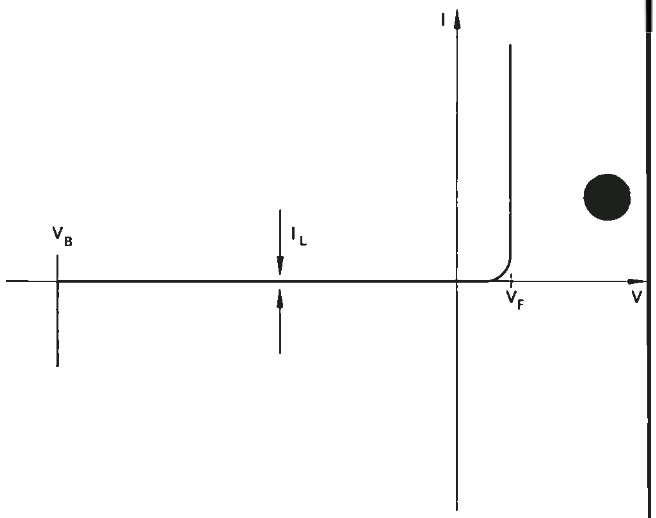


Fig. 1. Idealized V-I characteristics of a p-n junction

This approximates an increase in I_L by a factor of two for each 10°C rise in temperature and by a factor of ten for each 50°C temperature rise. If I_L is increased because of surface (or other) defects, its rate of increase with temperature can be less than the rate that is given by (3). At some elevated temperature, however, the faster rising term given by relation (3) will emerge as dominant.

In the forward bias direction, over an appreciable current range, V_F decreases about 1 mV for each 1°C temperature increase.

Figure 2 illustrates schematically a practical high-power-device mounting scheme. The pellet (silicon for this example) contains one or more p-n junctions, the temperature at a given junction being designated T_j. The device is bonded to the bottom of its case, only one section of which is shown in Fig. 2. The case temperature is T_c. In use, the case (package) is mounted on a heat sink, a portion of which is shown in Fig. 2. T_s is the heat sink temperature.

Heat is generated at the p-n junction, and is dissipated through the pellet and case to the heat sink. For linear heat conduction

$$\frac{dQ}{dt} = \frac{KA}{L} \Delta T \quad (4)$$

where

Q = quantity of heat (energy)
K = thermal conductivity
A/L = area-to-length ratio of specimen through which heat is flowing
ΔT = temperature difference

By analogy to electric-current flow,

$$\frac{dq}{dt} = I = \frac{\sigma A}{L} \Delta V \quad (5)$$

where

σ = electrical conductivity
ΔV = potential difference
q = electronic charge

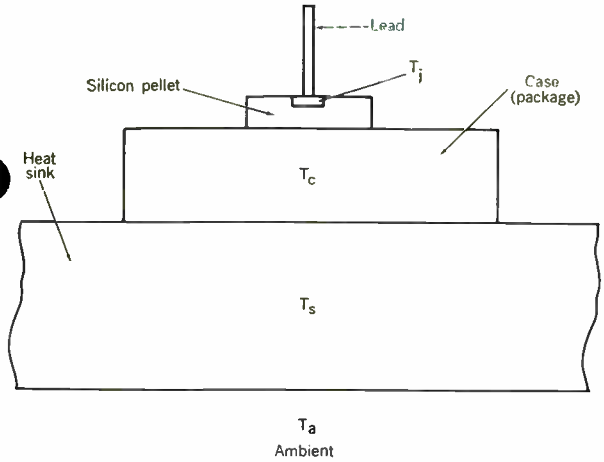


Fig. 2. Schematic diagram of heat-flow path from p-n junction to ambient for high-power device

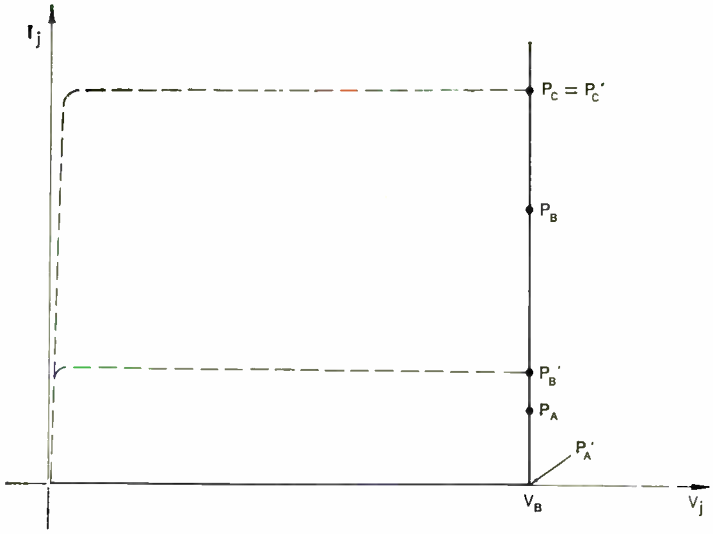


Fig. 3. A p-n junction rectifier that has been biased into the avalanche breakdown region

and also R = resistance = $L/\sigma A$. We can define a thermal resistance

$$\theta = \frac{L}{KA} \tag{6}$$

and

$$\frac{dQ}{dt} = \frac{\Delta T}{\theta} \tag{7}$$

Practical units for θ are °C per watt. An important difference between the thermal and electrical situations is that, since Q represents an energy, dQ/dt is a power, and can be equated to an electric power. For the case of a p-n junction under steady-state bias

$$V_jI_j = \frac{\Delta T}{\theta} \tag{8}$$

There are various thermal resistances that are specified. For example, from junction to case

$$V_jI_j = \frac{T_j - T_c}{\theta_{jc}} \tag{9}$$

From junction to heat sink

$$V_jI_j = \frac{T_j - T_s}{\theta_{js}} \tag{10}$$

From the nature of Eq. (4)—and perhaps more simply by analogy to electric circuits—thermal resistances in series can be added. For example,

$$\theta_{js} = \theta_{jc} + \theta_{cs} \tag{11}$$

This is really an approximation because the regions (Fig. 2) are not isothermal, and heat flow is not linear. Separate thermal resistances can be calculated for each region from a knowledge of K for that material and the heat generation pattern of the junctions. The latter is often difficult to ascertain. Interfaces between regions

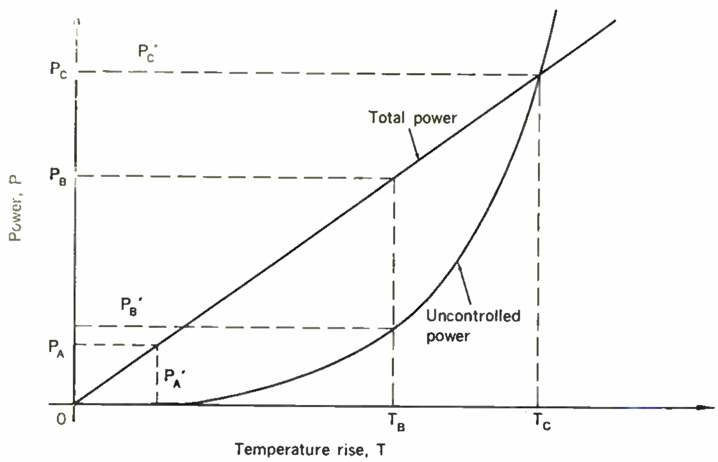


Fig. 4. Total and uncontrolled power curves for a device with given junction-to-heat-sink thermal resistance θ_{js}

may also add significant thermal resistances, and so must be taken into account in an equation like (11). A thin layer of silicone grease is often inserted between the case and heat sink before they are bolted together to improve conduction between the metal surfaces, which are not perfectly flat. Heat is transferred from the heat sink to an ambient by convection (free air) or by conduction to a stream of forced air or water. The latter technique employs water flowing through a tube brazed to the heat sink.

Electrical isolation of system parts is often necessary and the use of isolated heat sinks is generally impossible. Instead, a separate layer is provided between the case and heat sink during mounting, between two metal parts

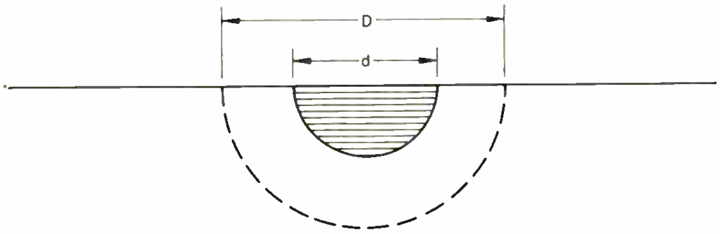
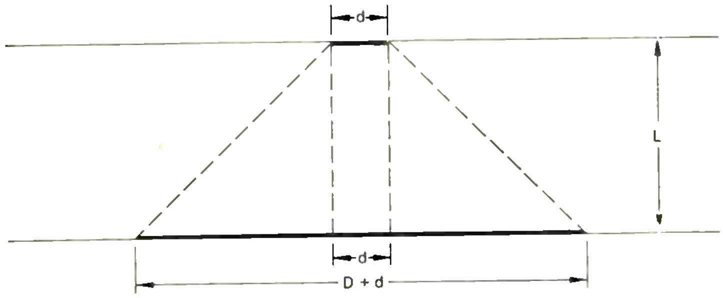


Fig. 5. Thermal spreading resistance from hemisphere of diameter d to one of diameter D is given by the relation $\theta = \frac{1}{\pi K}\left(\frac{1}{d} - \frac{1}{D}\right)$



$$\frac{\theta}{\theta_{S=0}} = \frac{\ln(1-S/D)}{S/D}$$

Fig. 6. Lowering of θ by the spreading of heat flow

of the case, or between the pellet and the case. A thin piece of mica (and silicone grease) is generally used between the case and heat sink, adding a thermal resistance in the range 0.2 to 0.5°C per watt. The other isolation schemes use thin metallized ceramic disks, generally of aluminum oxide. Recently beryllium oxide ceramics, which have much higher K values than aluminum oxide, have become available. Thermal resistances added by the ceramics are higher than that of mica because they are thicker; and, since heat flows in a spreading fashion from junction to heat sink, they have effectively smaller areas. For example, an alumina disk 0.1 inch in diameter and 0.02 inch thick has $\theta \approx 10$°C per watt from top to bottom (assuming uniform heat flow). Beryllia would have $\theta \approx 1$°C per watt, about twice the value of an equivalent piece of copper.

To illustrate thermal limitations in a simple manner, consider a p-n junction rectifier to be biased into the avalanche breakdown region, as shown by the points in Fig. 3 (axes shifted from Fig. 1). Power generated is then simply $V_B I_j$. Power dissipated is $(T_j - T_s)/\theta_{js}$, and equals the power generated for steady-state conditions. Three operating points—P_A, P_B, and P_C—are shown in Fig. 3. Shown dotted are the junction leakage currents, larger for the higher power conditions due to junction temperature rise. P_A', P_B', and P_C' are the values of power generated at the three operating points as the result of leakage current flow. Figure 4 represents these effects graphically.

The straight line plots total power $P = T/\theta = V_j I_j$. The exponentially increasing line represents uncontrolled power, $V_B I_L$, a power that cannot be utilized. The difference between the two curves is controlled (useful) power. At P_C, the total power is uncontrolled. For the given θ_{js}, points beyond P_C (Fig. 3) are not attainable because if we were to attempt to increase I_j the consequent temperature rise would increase I_L to a still higher value. This is called thermal runaway, which, if not safely limited, results in catastrophic burnout of the device. A stable power limitation point is P_B, where (Fig. 4) the rates of increase of the total (P_B) and uncontrolled (P_B') powers with temperature are the same. Below T_B, an increase in power dissipation within the device will result in a greater increase in heat flow to the heat sink than in uncontrolled power. By differentiating (10) with respect to T_j, assuming T_s constant,

$$V_j \frac{dI_j}{dT_j} = \frac{1}{\theta_{js}} \tag{12}$$

From Eq. (3),

$$0.1\ V_j I_j \approx \frac{1}{\theta_{js}} \tag{13}$$

Hence, for absolute stability,

$$V_j I_j < \frac{10}{\theta_{js}} \tag{14}$$

Although (14) was obtained for a simple case (Fig. 3), it applies to any operating mode of a device, where I_j is a leakage current.

Semiconductor p-n junction devices operate well at high power densities, and can fail so quickly as the result of thermal (or other) runaway that they are difficult to protect. Structures designed specifically for high-frequency operation are forced to operate at high power densities to minimize parasitic electrical effects. Hence, lowering thermal resistance is a major design consideration. Figure 5 illustrates the basic problem for a device with small junction area (approximated by a conductive hemisphere of diameter d). The spreading thermal resistance (from d to infinity) is $\theta_\infty = 1/\pi K d$. The thermal resistance from d to D, with $D = 2d$, is $\theta_{2d} = 1/2\pi K d$, or

Fig. 7. Schematic illustration of distribution of p-n junction structure, giving lower value of θ

Fig. 8. Schematic illustration of large-area p-n junction device designed for operation at high currents

Fig. 9. Schematic illustration of two devices connected in parallel in one package

Fig. 10. Schematic illustration of two separately packaged devices connected in parallel on a heat-sink member, thus forming a new, large package

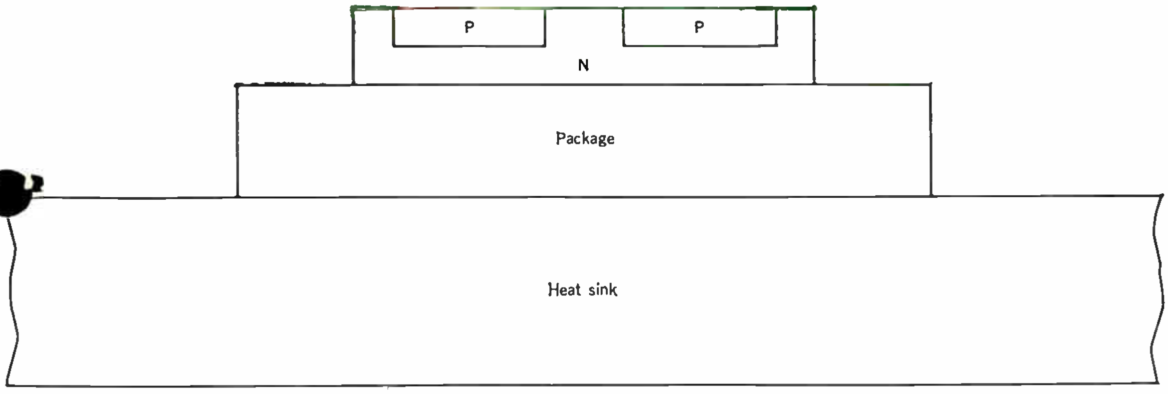


Fig. 7

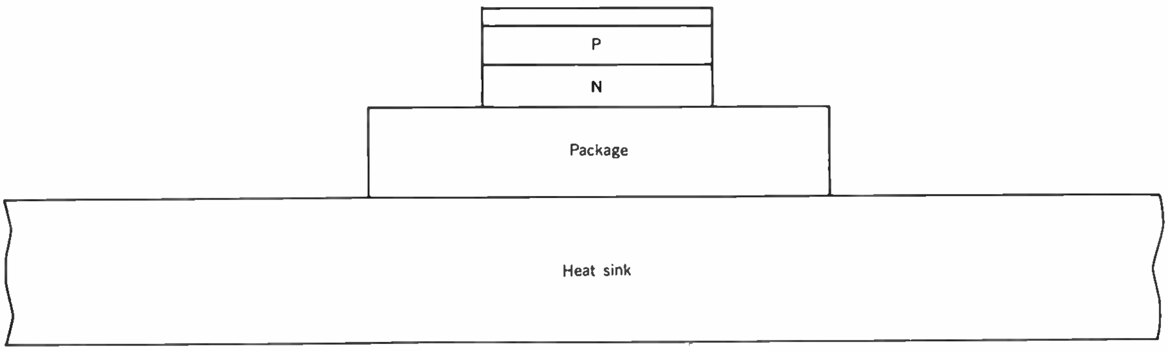


Fig. 8

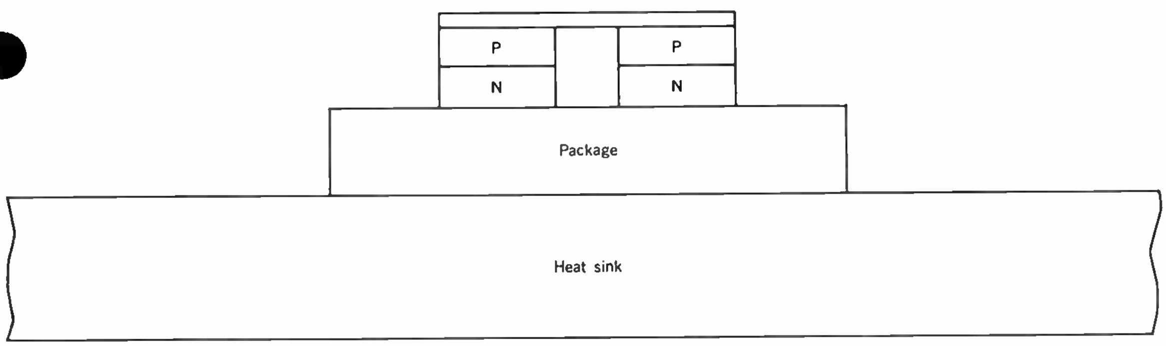
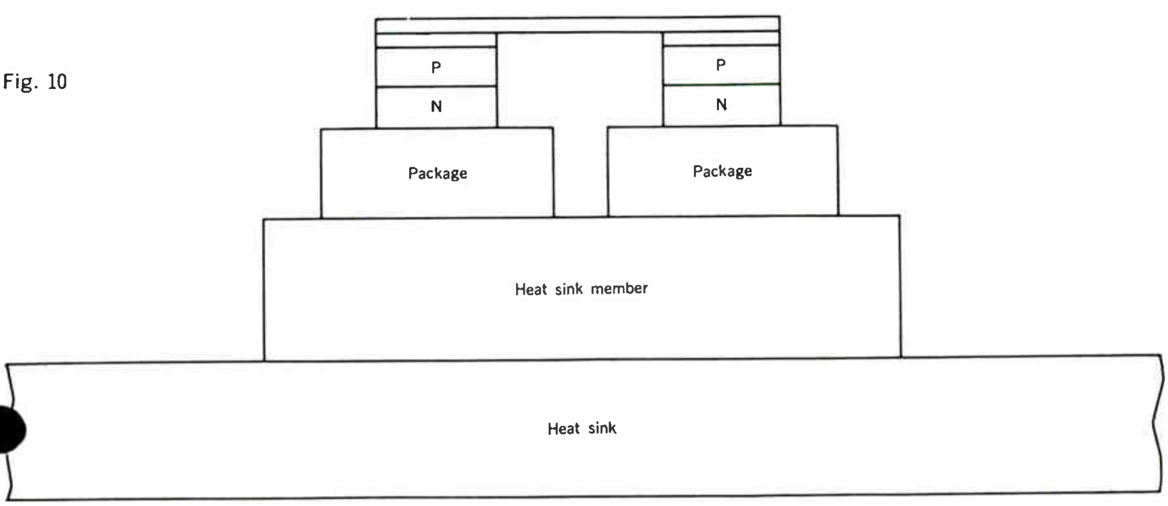


Fig. 9

Fig. 10



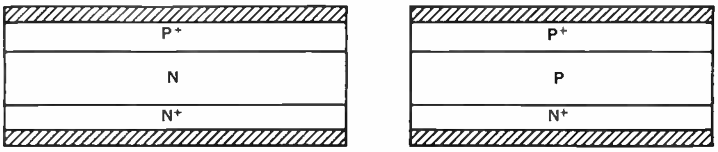


Fig. 11. Two internal geometries for power rectifiers

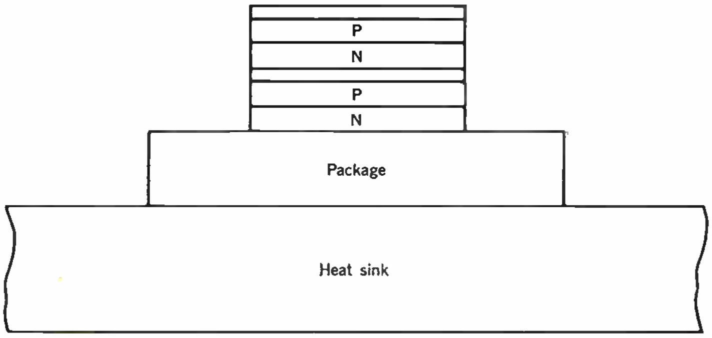


Fig. 12. Pellets stacked on top of each other in a package in order to increase reverse breakdown voltage

half the value of θ_∞. To a first approximation for small geometries, θ_{jc} may be taken as the sum of θ_{2d} and θ from $D = 2d$ to the case; see Fig. 6. For heat flow from an area of width D and unit length to one of width $D + S$

$$\theta = \frac{L}{KS} \ln\left(1 + \frac{S}{D}\right) \qquad (15)$$

$$\theta_{S=0} = \frac{L}{KD} \qquad (16)$$

$$\frac{\theta_{S=0}}{\theta_{S=10D}} = 4 \qquad (17)$$

Hence, lateral spread of heat flow is important in lowering θ. Figure 7 depicts schematically a device in which the junction geometry is split into two equal parallel parts for better electrical performance or lower thermal resistance. To take full advantage of heat-flow spreading, the two sections are not brought closer together than approximately the thickness of the pellet.

For operation at very high currents, devices having large areas are required, as shown schematically in Fig. 8. Since the largest crystals of silicon or germanium that can be grown conveniently are about 1.5 inches in diameter, a device that requires a larger size than this must be built in several parallel-connected parts. Also, from a practical standpoint, it is more difficult to make large-area p-n junction structures at a high yield than small ones, because of crystal defects and process limitations. Another limitation on the size of a single structure that may be built is thermal expansion coefficient mismatch between the silicon and its large-area metal contacts. If a hard solder connection is used, the silicon pellet may be strained, or may shatter upon cooling down from the bonding temperature. If a soft solder connection is used, the solder may rupture upon repeated temperature cycling (thermal fatigue). To solve these problems, smaller devices can be connected in parallel in a package (Fig. 9), or perhaps connected in parallel on a heat-sinking member and then perhaps repackaged for mounting on a larger heat sink (Fig. 10). These multiple device arrangements permit selection and matching of units before interconnection.

Power rectifiers

Solid-state power rectifiers are single p-n junction devices, made according to either of the geometries illustrated in Fig. 11, where p^+ and n^+ are very-low-resistivity p-type and n-type regions, respectively. The power rating of a rectifier is increased by increasing its reverse avalanche breakdown voltage and current-handling capacity, consistent with packaging to provide adequate thermal dissipation. The reverse breakdown voltage of a single silicon cell is limited to about 2 kV for practical reasons, and most rectifiers have absolute maximum peak reverse voltage ratings of under 1 kV. As cell size increases, so do the difficulties in producing cells that are free from defects, and hence, the voltage rating decreases. Reverse voltage can be increased by stacking two or more silicon pellets on top of one another; see Fig. 12. This method is not in common use, however, because the forward voltage drop is doubled and, even worse, the thermal resistance of the top cell is increased by a large factor. High-voltage cells generally have their p-n junctions covered with silicone varnish, and may be packaged with a gas under pressure, to prevent arcing across the p-n junction in the package.

If a reverse line transient drives a rectifier into its reverse avalanche breakdown region, the device should recover provided the average power is not sufficient to produce thermal runaway. It can happen, however, that reverse avalanche breakdown occurs first in a localized region, generally at the surface. Appreciable current (at high voltage) flowing through such a localized region can result in a local thermal runaway, which destroys this part of the cell and, as a consequence, generally makes its overall characteristic unusable. Hence, the cell must be protected from receiving reverse transient pulses by various means. To prevent surface breakdown from occurring before bulk breakdown, various schemes for lowering the surface electric field are being used. Figure 13 illustrates one of these schemes—that of shaping the pellet surface. By this technique, 1000-volt rectifiers have been made that can be pulsed nondestructively to 100 amperes in the reverse avalanche region, giving a peak power of 100 kW.

In the forward direction, single-junction rectifiers are rated to average currents of about 500 amperes, with peak surge current ratings (1/120 second) of twenty times this value. Pulsed operation takes advantage of the extremely high instantaneous thermal gradient (and hence, large heat flow) produced by fast heating of a junction in contact with the relatively cool body of the adjacent semiconductor. Junction defects are not so important under forward bias, because they generally result in regions of low current density and, hence, low power. Adjacent normal areas heat the defect areas by conduction through the silicon, making them more

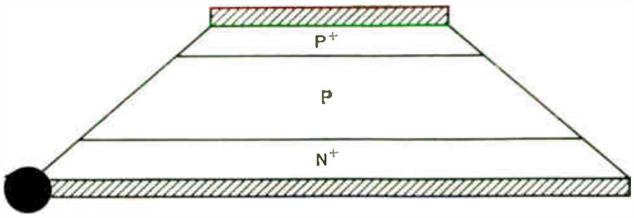


Fig. 13. Surface-contoured rectifier cell designed to prevent surface breakdown from occurring before bulk breakdown

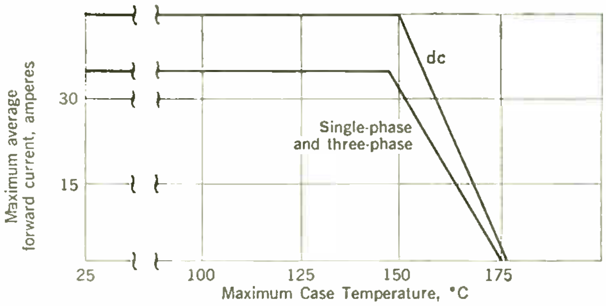
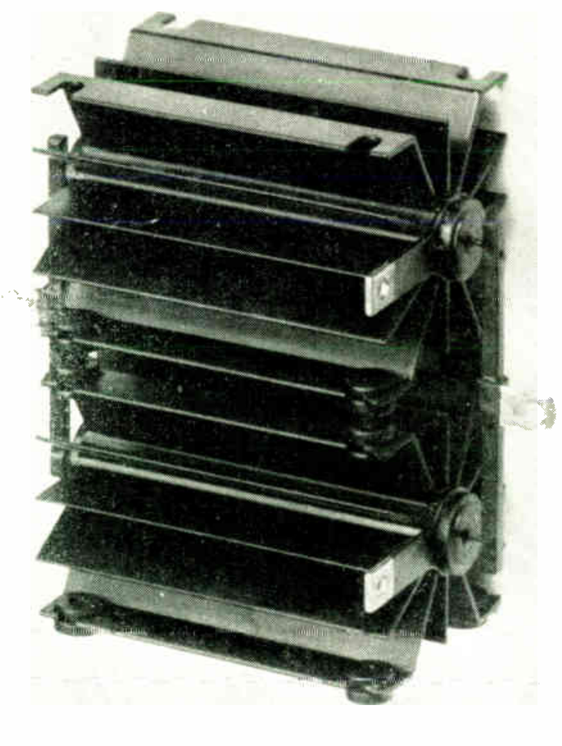


Fig. 14. Derating curve for 35-ampere stud-mounted rectifier (resistive or inductive load)

Fig. 15. An example of a small rectifier stack assembly

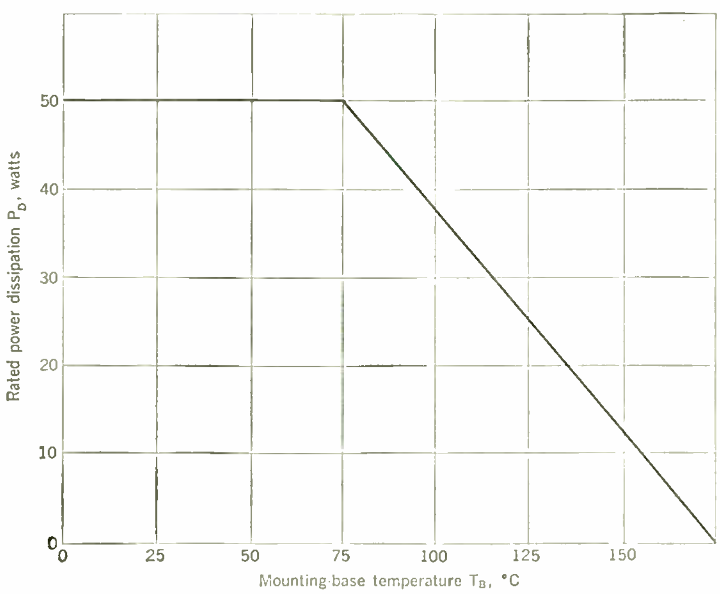


efficient, thus tending to make current flow more uniform. The forward current carried by a p-n junction cell of a given size is limited by the increase in forward voltage drop that takes place at high currents due to its very small, but finite, series resistance. This additional voltage drop reduces circuit efficiency and increases power generation. Germanium rectifiers are used primarily in a few selective applications that take advantage of their very low (<0.5 volt) forward drop. For example, in electrochemical refining, where enormous currents are used, the high forward efficiency results in a considerable savings in power.

Until T_j becomes appreciable, almost all the power generated in a rectifier is under forward bias. Hence, forward current must be derated at elevated case temperatures. As shown in Fig. 14, for a 35-ampere stud-mounted rectifier having $\theta_{jc} \approx 1°C$ per watt, no derating is necessary until a case temperature of 150°C is reached. Although most rectifiers operate at line-power frequencies, some have been designed for higher-frequency use and fast switching. For example, 30-ampere rectifiers are available that have 99 per cent rectification efficiencies to beyond 150 kc/s and recovery times, from forward operation to a high reverse resistance, of less than 0.2 μs.

Very-high-current rectifiers are being made by the paralleling concept illustrated in Fig. 10. Individual cells are selected for forward match to within 1 per cent before assembly, and are aided to some extent in uniform current distribution by thermal flow from the heat sink to cooler-running (higher forward voltage) cells. A further advantage of this type of construction (rather than a single, hermetically sealed package) for very-high-current rectifiers is that a very large, current-carrying hermetically sealed member is not required. A seal that is large in area and that will withstand stresses caused by thermal cycling is extremely difficult to make.

Fig. 16. Power-temperature derating curve for a zener diode having a power dissipation of 50 watts



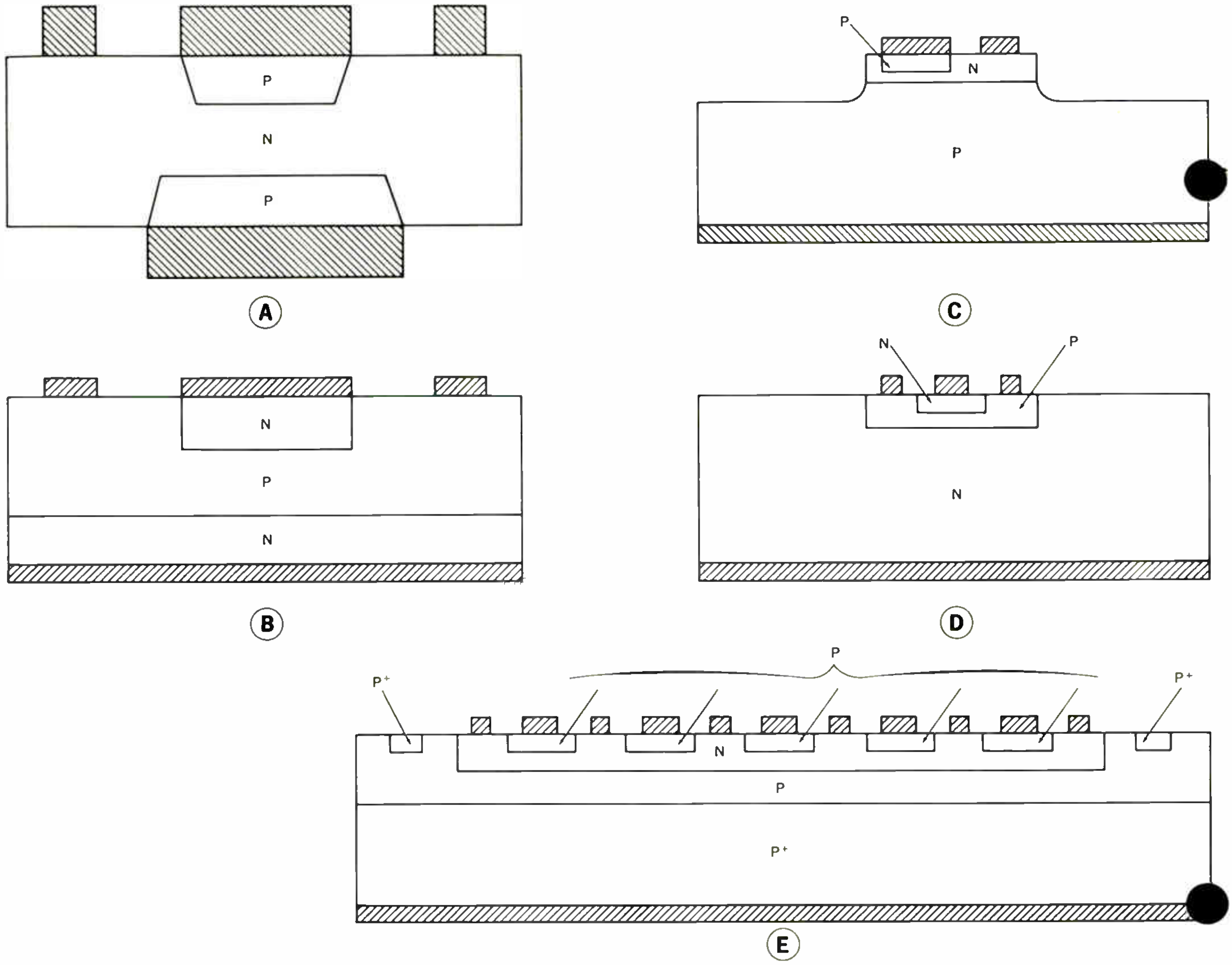


Fig. 17. Common transistor geometries, in cross section. A—Germanium alloy. B—Silicon diffused. C—Germanium mesa. D— Silicon planar. E—Silicon annular (interdigitated)

Rectifier stacks are assemblies of separately heat-sunk rectifiers to perform specific functions. One type of small stack is shown in Fig. 15. A great many series, parallel, and bridge arrangements are possible.

Power zener diodes

The zener diode is a regulator utilizing the almost constant-voltage region following reverse avalanche breakdown of a p-n junction (V_B in Fig. 1).

Although the term "diode" is generally reserved for low-power units and the term "rectifier" for high-power units, common usage is such that "zener diode" refers to all power levels of this device. Zener diodes with dissipations up to 50 watts are available, covering (in the high-power region) voltages from 6.8 to 200. A typical derating curve is shown in Fig. 16. The major effect of a rise in T_j is to increase the avalanche voltage. Temperature coefficients of zener diode avalanche voltage range from 0.1 per cent per °C for 200-volt units down to 0.04 per cent per °C for the 6.8-volt device. A 50-watt zener diode is packaged like a stud rectifier, or in a single-ended case.

Power transistors

There are several generic types of power transistors in common use: germanium alloy, germanium mesa, silicon alloy, and silicon diffused. Each type has several modifications, a few of which are sketched in cross section in Fig. 17. Like the rectifier cell, the transistor is limited in voltage operation to the breakdown potential of a single p-n junction and, although limited in current density by some basic considerations, can be extended to higher current levels by an increase in area.

Both n-p-n and p-n-p transistors can be made in silicon or germanium by each of the processes used, although in some cases one type has emerged as predominant. Hence, almost all germanium power alloy and mesa transistors are p-n-p, and most silicon power alloy and diffused units n-p-n. For some applications, matched n-p-n and p-n-p types can lead to circuit simplification. A rather close match can be obtained in some cases (such as silicon diffused base), but tight matching, particularly at high frequencies, is difficult because of inherent differences in device physics of the two types.

Transistors can be utilized in circuits in three different configurations: common base, common emitter, and common collector. Since the common-emitter configuration is by far the most frequently employed, and also best exhibits the use and limitations of power transistors, it will be the only type discussed. The emitter is common to input and output characteristics, the input is between base and emitter (I_B, V_{BE}), and the output is between collector and emitter (I_C, V_{CE}).

Historically, the germanium alloy power transistor was the first power transistor worthy of the name. These transistors are generally made as shown in Fig. 17(A), although many modifications, such as the diffused-base type, are used. For these devices, $\theta_{jc} \approx 0.5°C$ per watt, so with a mica isolator, $\theta_{js} < 1°C$ per watt. When mounting is on a convection-cooled heat sink, θ_{ja} can be as low as 3°C per watt.

Some power transistor limitations can be visualized by considering the common-emitter characteristics of a germanium alloy unit, such as shown in Fig. 18. Operational limitations for this type of unit are now imposed by BV_{CEO} (collector–emitter breakdown voltage with open base) values generally less than 200 volts. The value of BV_{CEO} is determined by reverse avalanche breakdown of the collector junction, and is often lower than this (see Fig. 18) as the result of current gain and surface effects. Since high current gain (at low currents) tends to reduce BV_{CEO}, it is doubtful that the present limit will be extended very much. Laboratory structures with high gain to 400 amperes have been made, but the marketing potential has not warranted their appearance as a product. Germanium alloy power transistors have very low values of $V_{CE(sat)}$, 50 mV at 50 amperes being attainable. Although this does not represent a very large power (2.5 watts), it is not negligible. The low $V_{CE(sat)}$ value attainable with these units makes possible efficient operation with low-voltage sources such as thermoelectric generators, solar cells, fuel cells, and sea-water batteries. Because of their wide bases and high h_{FE}, germanium alloy power transistors generally have serious gain falloff above 10 kc/s. Diffused-base types are usable in the radio-frequency range and as high-current switches, with fall times under a microsecond.

Germanium alloy power transistors are rated to power levels of just under 200 watts at a 25°C case temperature. With $\theta_{jc} \approx 0.5°C$ per watt, these units are linearly derated to zero power at 110°C. A constant-power curve is shown in Fig. 18. For a given thermal environment, a curve of this type then defines the limit of dc operation, even though useful transistor characteristics extend beyond the curve and could be utilized in a more efficient thermal environment. For an amplifier application, the average power generated must be considered. This will vary tremendously depending on whether class A, B, or C is used. For a switch application, not only must the power generated in the OFF and ON positions be considered, but also the power generated during switching. The latter is a function of switching speed and load-line shape, which may be far from linear for reactive loads. For fast switching, the transistor may safely traverse extremely high power regions. Thermal time constants

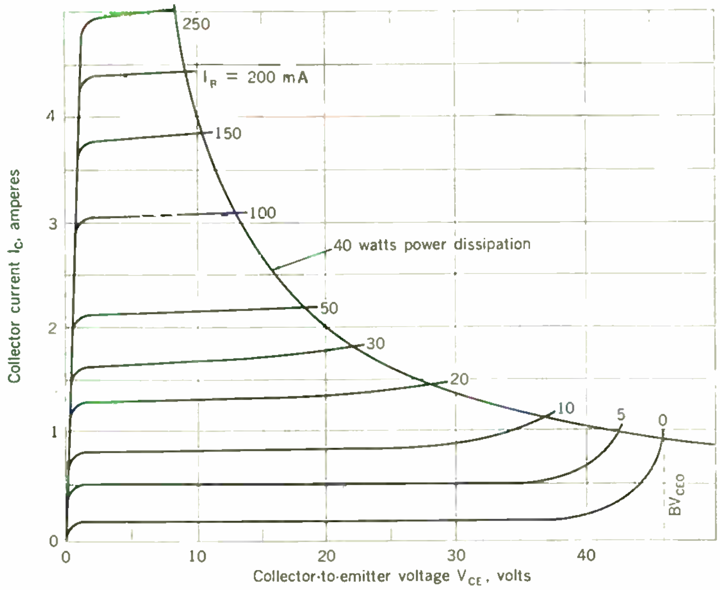
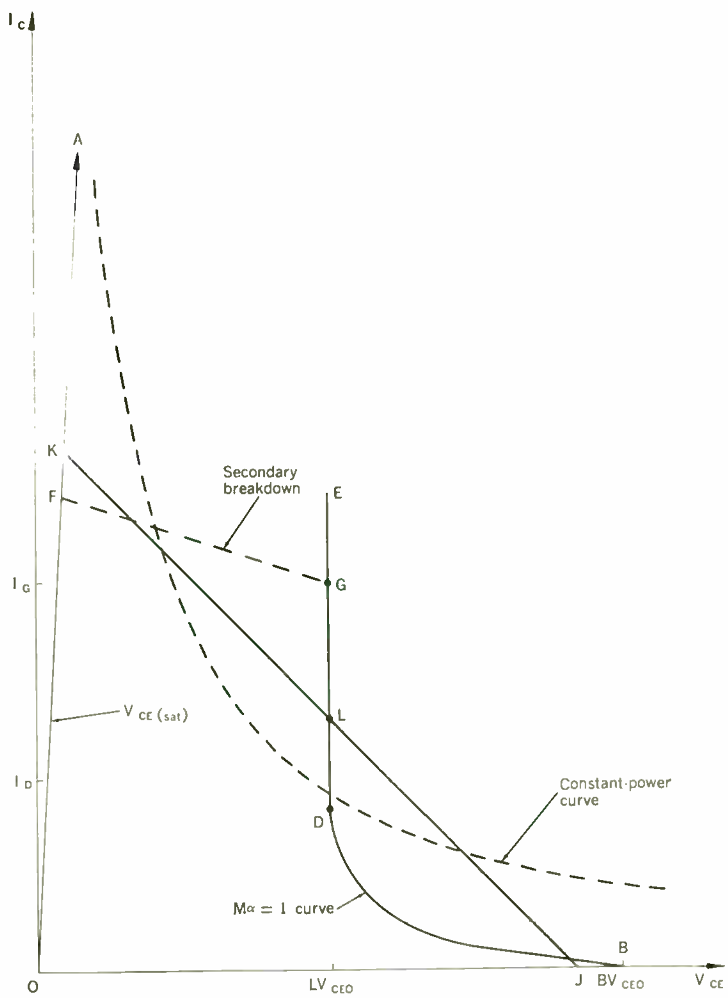


Fig. 18. Common-emitter characteristics of a typical germanium alloy power transistor

Fig. 19. Avalanche switchback and secondary breakdown in collector V-I characteristics, common-emitter connection



are in the range of 50 ms for these transistors, so during each switching pulse the time spent in high-generation regions must be considerably less than this to utilize powers higher than the dc rating.

Silicon n-p-n alloy power transistors are limited to about 30 amperes, but are rated up to 250 watts, 250 volts BV_{CEO} and can operate to 175°C. They have much lower current gains (about 20) and much larger values of $V_{CE(sat)}$ than germanium units of similar geometry (well over 1 volt at rated current). Silicon diffused transistors of similar geometry, Fig. 17(B), are available in ratings up to 300 watts, with a minimum h_{FE} of 10 at 50 amperes and BV_{CEO} of 150 volts, and are derated to zero power at a case temperature of 200°C.

Power transistor operation would be relatively simple if the only operational and power limitations were those already discussed. Unfortunately, there are several complicating factors. These are illustrated in Fig. 19, which shows only the curves limiting the area of operation of a transistor. The $V_{CE(sat)}$ curve OA is similar to that in Fig. 18. Figure 19 shows a BV_{CEO} value equal to the collector–base junction breakdown voltage. This is the case where the transistor is free from punchthrough (collector junction depletion region reaching the emitter junction) and surface breakdown (caused by surface impurities and imperfections), and has a low value of leakage current. Leakage current I_{CEO} along OB is not differentiated from the V_{CE} axis because of its small value. As the transistor is driven beyond breakdown (base open), the characteristic follows along the curve $BDGE$. From B to D, collector–emitter voltage drops as current increases. This part of the characteristic is determined by the equation $M\alpha = 1$, where M is the avalanche multiplication coefficient (a function that increases with voltage) and α is the low-voltage common-base current gain. As collector current is drawn beyond BV_{CEO}, α increases, so M must decrease to keep $M\alpha = 1$. Hence, collector voltage decreases. At higher currents, h_{FE} stops rising, so the negative-resistance region terminates (point D) in a low-value positive-resistance region DGE at a voltage LV_{CEO}. The avalanche switchback from BV_{CEO} to LV_{CEO} is approximately 50 per cent for germanium p-n-p and n-p-n as well as silicon n-p-n transistors but, due to a lower avalanche coefficient, is only about 20 per cent in silicon p-n-p transistors. To the right of $BDGE$, between LV_{CEO} and BV_{CEO}, the common-base current gain $h_{FE} = M\alpha$ is greater than unity. Operation in this region in the common-base configuration is possible, as long as the circuit is properly designed to accommodate the greater-than-unity current gain. The region DG can be shifted to voltages higher than LV_{CEO} by reverse biasing the emitter–base junction and, in some cases, can approach BV_{CEO}.

At point G in Fig. 19, a secondary breakdown region GF is indicated. Secondary breakdown is a phenomenon that appears to occur in all transistors, although in low-power types it is often entirely beyond the rated power and, in such cases, can be neglected. In high-power transistors, it is a major problem and can restrict the operating range far below the limitations produced by ordinary thermal considerations.

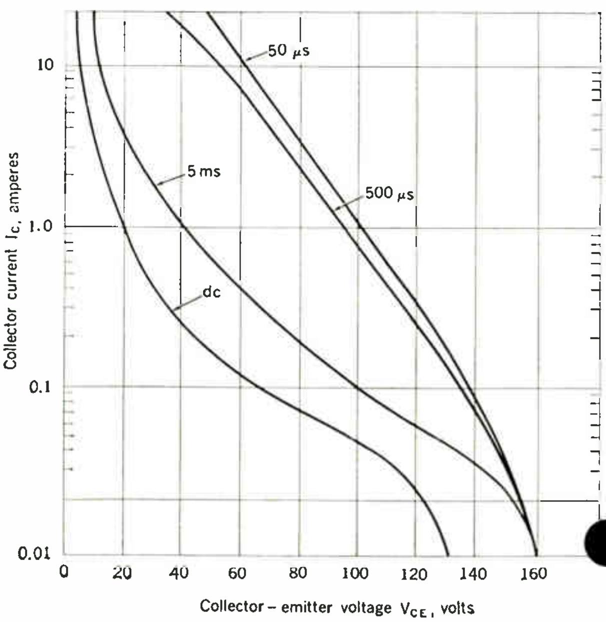
Several mechanisms are recognized as being capable of causing secondary breakdown, and they often act in combination. One is caused by defects that concentrate current in small areas. These defects may be regions of higher current gain due to localized, thin base sections. The local power density becomes very large, and local thermal runaway occurs. Another mechanism involves a greater temperature rise at the middle of a large structure (see Fig. 6) than at the edges, since the edge regions take advantage of thermal spreading. A defect near the center of a large structure will invoke both mechanisms.

Transistors having high-resistivity base regions, so that uniform punchthrough can easily occur, display a third type of secondary breakdown. This is caused by constriction of emitter current to a small region near its center as the result of biasing by radial base current flow. This effect is particularly active along DGE, Fig. 19, in which region a large majority current flows from collector to base. Here an emitter–collector voltage drop from G to F (secondary breakdown) can occur with no requirement for temperature rise, although the constriction of current to a small region often produces one. The secondary breakdown condition is made worse (that is, I_G is lowered) if the emitter–base junction is reverse biased; or improved (that is, I_G is raised) for forward emitter–base bias. Here, also, defects complicate the picture.

A fourth secondary breakdown mechanism appears when the contact to the collector region is injecting, and may be caused by a nonintentional, perhaps not even continuous, p-n junction, or a tunneling process. The transistor (from emitter to collector) assumes a p-n-p-n appearance (like a silicon controlled rectifier). This type of structure is regenerative, and switches to a lower voltage at the current I_G. If the undesired injecting structure is nonuniform, current can be localized. Secondary breakdown is often destructive because of current (and hence, power) concentration that can cause local thermal runaway.

For purposes of amplification, transistor operation is

Fig. 20. Curves of safe operating area for a typical germanium alloy power transistor with various switching times



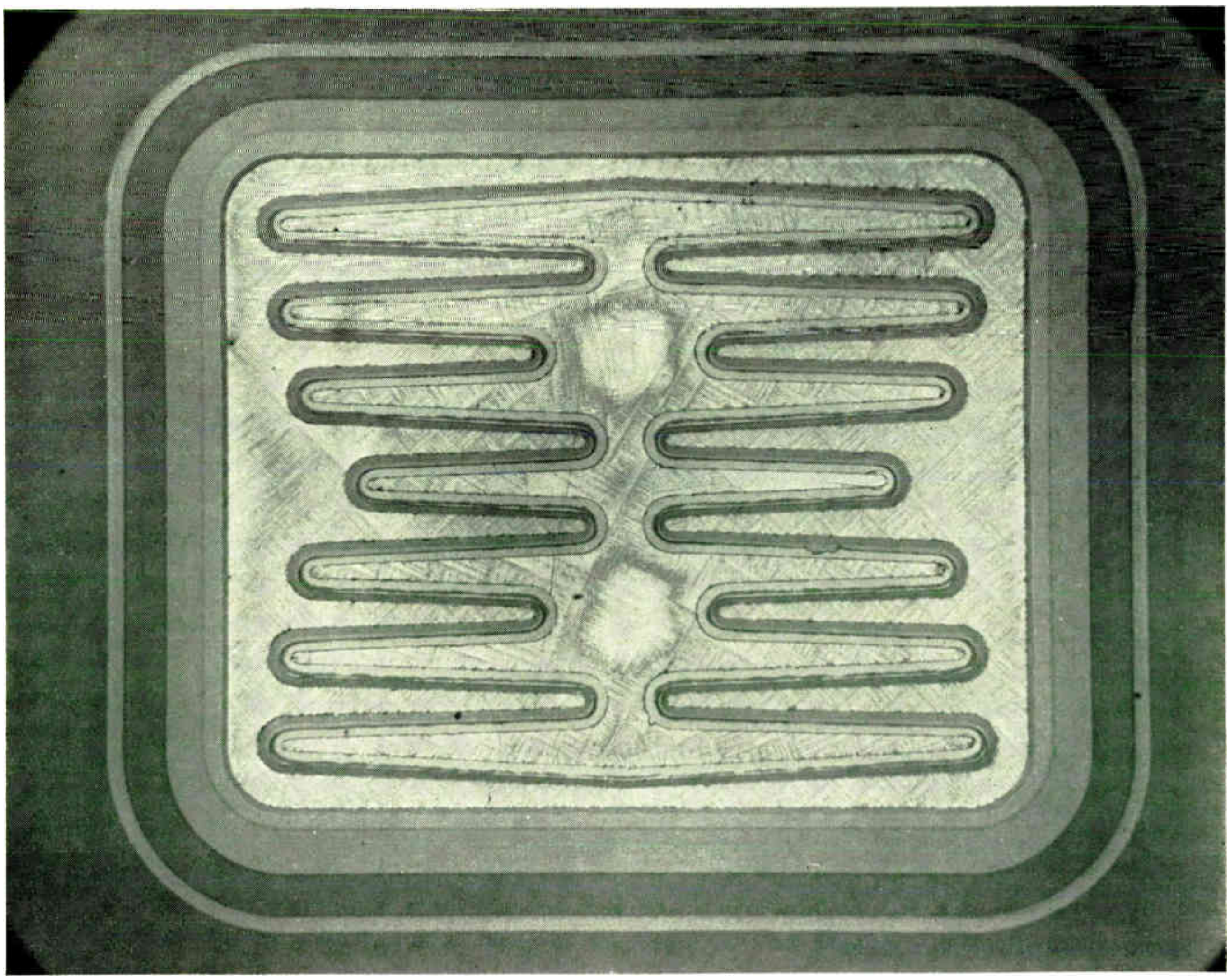
limited (Fig. 19) to the region enclosed by *OBDGFO*, with the additional limitation that power generated must be within the rated limit. This region, called the safe area, is specified for a given transistor as shown in Fig. 20. An amplifier load line will be entirely within the safe area. For switching applications, since we are concerned only with the end points and not with the linearity of characteristics in between, the load line may violate all limiting curves as shown by *JK* in Fig. 19.

One item of concern in this case is the power generated during switching, which must be kept below the power that results in thermal runaway in any of the violated regions. The faster the switching, the less the power generation, so safe-area curves may be extended (Fig. 20). Another item of concern is latch-up at point *L* in Fig. 19. Since *L* represents a stable operating point, the transistor can end up there during the turnoff cycle instead of returning to point *J*. If the power generation at point *L* is beyond the transistor rating, it will undergo thermal runaway. It is necessary, then, that the turnoff pulse be not only sufficiently fast to avoid thermal problems, but sufficiently strong to carry the transistor back to point *J*.

The germanium mesa transistor has a diffused base region and alloy emitter, as shown in Fig. 17(C). It derives its name from the shape of the active area that is formed by etching down the remainder of the original pellet surface. Although originally designed for low-power high-frequency operation, larger-area versions mounted in packages designed for better thermal dissipation are useful into the range of several watts. Germanium power mesa transistors are usually limited to a BV_{CEO} of 25 volts and collector current of ½ ampere. Usable to about 250 Mc/s for communication applications, they provide, for example, about ⅔ watt output RF power at 160 Mc/s with greater than 50 per cent efficiency.

Silicon diffused-base power transistors are almost

Fig. 21. High-power silicon interdigitated epitaxial annular transistor pellet. Size is approximately 0.5 inch square. Tapered emitter (center) fingers can be used to reduce emitter area because current decreases down a finger due to its distributed flow into the base



always made using masked diffusions for base and emitter, giving structures like those shown in Fig. 17 (D) and (E). This type of construction (as does the germanium mesa) allows the formation of extremely thin bases, less than 0.5 micron in many cases. Since the transport time of minority carriers across the base region is inversely proportional to the square of the base width, frequency response of these units can be very high. A narrow base creates an additional problem, however, in that the sheet resistance of the base region becomes very high. Base current flowing laterally between emitter and collector creates an electric field in such a direction (for $h_{FB} < 1$) that a somewhat higher emitter junction forward bias is produced at its periphery than toward its center. Since current injected from emitter to base is an exponential function of junction voltage, a small potential difference leads to a high degree of emitter current crowding toward the periphery. Hence, the central parts of the emitter carry little current, but do add a large parasitic junction capacitance. The obvious result has been to utilize geometries that concentrate on "line" emitters, such as a narrow stripe or ring. Where larger current capability is desired, geometries are used that effectively place many line segments in parallel, such as an interdigitated structure; see Figs. 21 and 17(E).

The structure shown in Fig. 17(D) will have a relatively high value of $V_{CE(sat)}$ due to the ohmic drop caused by collector current flowing through the rather high resistivity (of the order of 1 ohm·cm) collector region. As the geometry is made more "linear," electrical and thermal spreading resistance become important, particularly since current flow through the base and into the collector is constricted to a path about the size of the emitter. The electrical (but not the thermal) resistance can be very much reduced by utilizing a collector that has a thin (generally 10–50 micron) high-resistivity region (so that a high collector-junction breakdown voltage may be achieved) backed up by a very low resistivity region (generally 100–250 microns); see Fig. 17(E). Thickness of the high-resistivity region is greater the higher the breakdown voltage. A much thinner pellet with just the high-resistivity region would work even better, but breakage in processing would be excessive. It is important, however, from the thermal standpoint, to keep the pellet as thin as practically feasible. Two-layer collector structures (n-n^+ or p-p^+) are produced primarily by the epitaxial process, wherein the high-resistivity layer is grown on the low-resistivity substrate. Epitaxial growth and localized (masked) diffusion are the two "breakthroughs" without which silicon high-frequency power transistor technology would be far below its present level of perfection.

Base transport time (base width) is not the only factor determining speed of a transistor. The other major limiting factors are controlled by junction capacitance and diffusion capacitance (charge storage) effects. Each p-n junction behaves very much like a capacitor in parallel with the mechanism producing nonlinear *V-I* characteristics (Fig. 1). These parasitic capacitances degrade performance of high-frequency amplifiers by virtue of the resulting *RC* time constants. If the emitter junction is made as narrow as possible, its capacitance is reduced. The collector junction is also kept as small as possible for the same reason. Practical process limitations impose restrictions on how fine a structure can be made. Lateral spacings and line widths in the 5-to-10-micron range are handled reasonably well at present. Collector capacitance can be reduced by raising collector resistivity. At high current densities, however, this permits the effective base width to increase, and hence the frequency response is lowered by virtue of a longer base transport time. This technique limits the power handling capability of the transistor, but is very useful in automatic-gain-control applications.

The gain–bandwidth product of a transistor $f_T = \sqrt{Gf}$, is a measure of how fast a signal can travel from emitter to collector, and includes emitter and collector junction capacitance charging times (*RC* products), base transport time, and collector depletion layer transit time. At f_T, $h_{FE} = 1$, but power gain exists because of impedance transformation. In Fig. 22, f_T is plotted versus collector current for a 10-ampere silicon diffused-base transistor (Fig. 21). The drop-off at low currents is due to

Fig. 22. Gain–bandwidth product f_T vs. collector current for two types of 10-ampere diffused-base silicon transistors

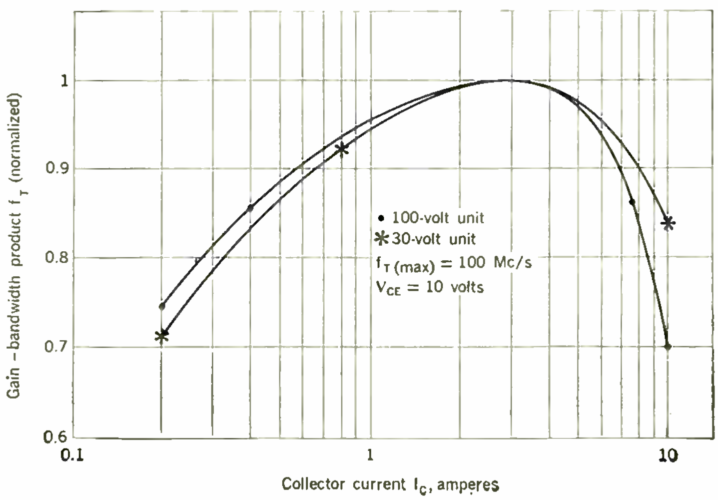
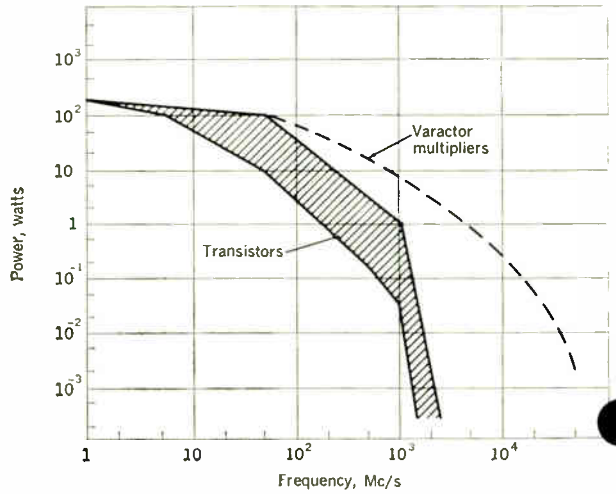


Fig. 23. Power vs. frequency for silicon high-frequency power transistors and varactors



increasing emitter junction time constant since emitter junction resistance $R_E = 1/(dI_E/dV_E)$ is inversely proportional to I_E. The drop-off at high currents is due primarily to effective base widening, and is much more severe for the higher voltage (higher collector resistivity) unit.

Although f_T is an important measure of the ability of a transistor to amplify at high frequencies, a more important figure of merit for amplifier use is the maximum frequency of oscillation

$$f_{max} \approx \frac{1}{5}\sqrt{\frac{f_T}{r_b'C_c}} \quad \text{if } f_{max} \gg f_T \qquad (18)$$

As base width is reduced to increase f_T, r_b' increases because of inherent process limitations, and f_{max} may actually drop. Hence, for amplifiers, f_T is often lowered so that f_{max}, and hence, amplifier performance, is optimized.

The present status of silicon high-frequency power transistor amplifiers is illustrated in Fig. 23. The shaded curve represents upper limits of powers attainable with usable efficiencies. The lower part of the shaded area depicts transistors that can be made with reasonable yield and the upper part indicates transistors that have been demonstrated as laboratory models. Because of thermal limitations imposed by the fine geometrical designs, above approximately 100 Mc/s these transistors are generally distributed over the surface of a larger silicon pellet. The parts are made as separate lower-current transistors (see Fig. 7) and then interconnected in parallel by metalizing. Conducting paths then form over the surface of the silicon dioxide passivating glass, approximately 1 micron thick, that covers the silicon. Contact to appropriate silicon regions is made by cutting holes in the glass. Metalized paths drop down from the outer oxide surface and alloy to the silicon in these regions. Although some (or all) of the interconnections could be made by connecting p-n junction geometries, over-the-oxide interconnections have lower parasitic capacitance and, hence, are essential for the ultimate in transistor high-frequency performance.

High-frequency transistors are often used in parallel (see Fig. 10) to increase power output. High-frequency power silicon transistors are often difficult to use in low-frequency applications because of their tendency to oscillate in practical circuits. If the base is widened to lower the frequency response, current gain drops because minority carrier lifetime in the low-resistivity base regions produced by this type of process tends to be low. Diffused-base transistors in the 10-ampere 100-volt range have been successfully made with f_T values as low as 10 Mc/s. Lower than this, geometries such as that shown in Fig. 17(B) are used.

The current gain–bandwidth product f_T is a good indicator of how fast a transistor can be switched on. To turn it off, however, requires removal of the minority carriers stored in the base and collector regions while in the (saturated) "on" condition. Fastest switching is accomplished by lowering minority carrier lifetime (by gold diffusion) to a very small value so that the injected minority-carrier stored charge will quickly recombine once turnoff is started. Transistor design to minimize stored charge is also important. Very low lifetimes indicate very thin bases, so that a reasonable

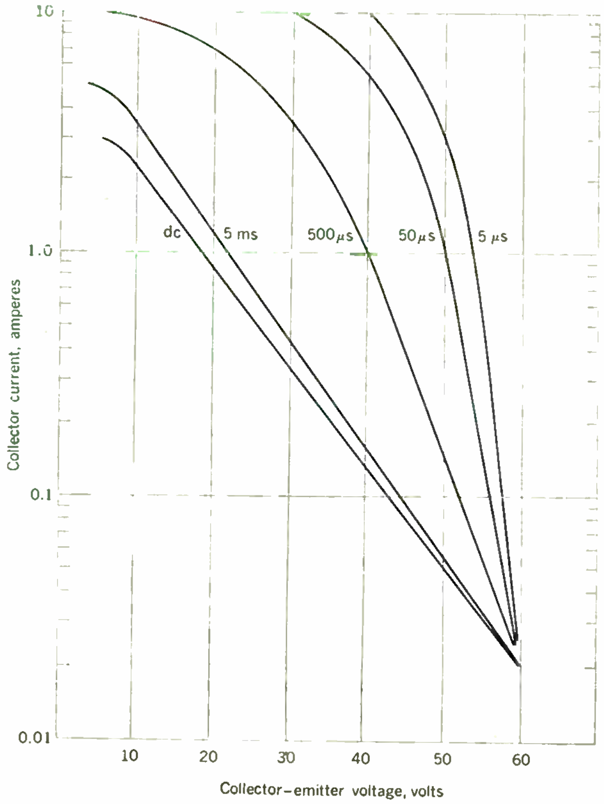
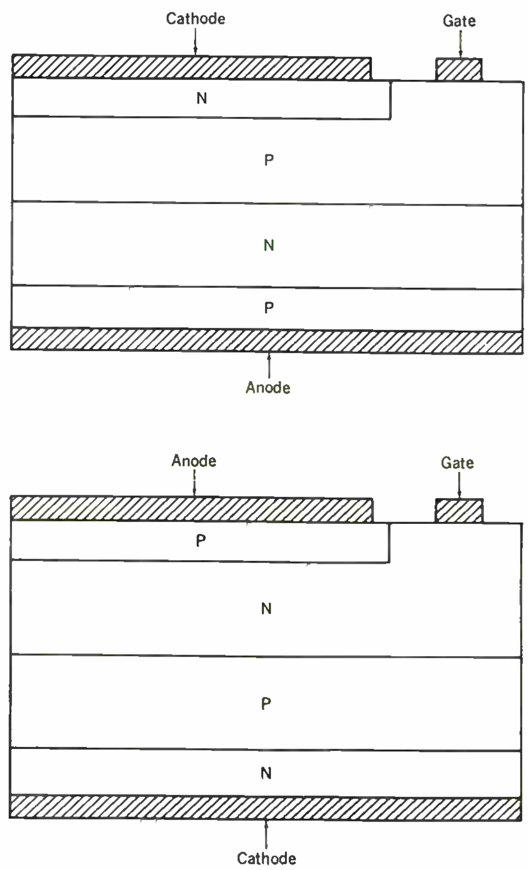


Fig. 24. Safe-area curves for a typical high-power diffused-base silicon transistor with various switching times

Fig. 25. Junction structures in the two SCR polarity types



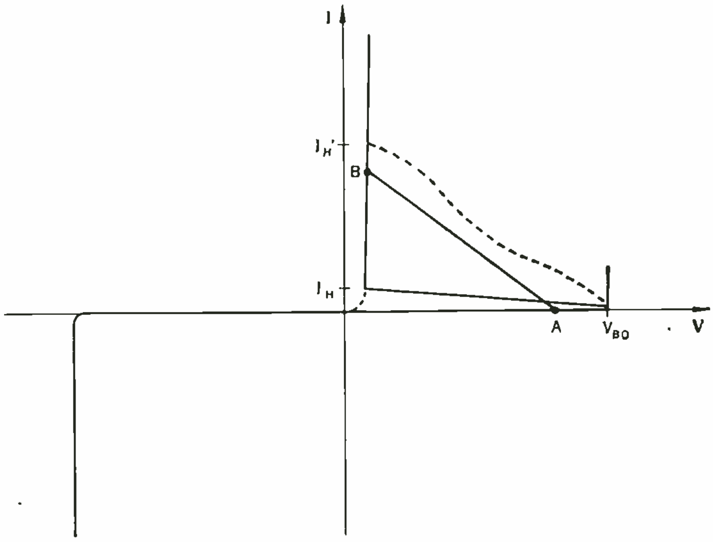


Fig. 26. V-I characteristic of a silicon controlled rectifier

current gain will be preserved. At present, transistors are available with switching times of approximately 10 nanoseconds for currents in the low ampere range.

Thermal limitations for diffused-base power transistors are similar to those for other transistors, and safe-area curves are necessary (Fig. 24). Because of the very thin bases of these structures, large-area versions are prone to be limited by defect-induced secondary breakdown.

Silicon controlled rectifiers

The silicon controlled rectifier (abbreviated SCR) is a four-layer device utilizing three p-n junctions for its operation. Like the transistor, two polarity versions are possible, as shown in Fig. 25, the most commonly used version being shown at the top. The SCR is used as a three-terminal switch, such that anode-to-cathode switching from a high voltage–low current (off) state to a high current–low voltage (on) state is triggered by a small gate signal. In order to return the SCR to its high-impedance state, the anode-to-cathode current is reduced below a critical hold current I_H. Figure 26 illustrates the V-I characteristic of an SCR. As voltage is increased in the positive direction (center junction reverse biased) a small leakage current flows until the avalanche breakdown voltage V_{BO} of the center junction is reached (or until surface breakdown occurs). Past this point, appreciable current can flow. As with the transistor, the V-I characteristic from V_{BO} to I_H is governed by the equation $M\alpha = 1$, except that since now there are two transistors, each utilizing the reverse-biased center junction for a collector, the equation in this case is approximated by $M(\alpha_{npn} + \alpha_{pnp}) = 1$. As the current increases, α_{npn} and/or α_{pnp} increases, so the voltage drops to reduce M. Whereas in the case of a transistor this avalanche switchback is undesirable, in the case of an SCR we wish to maximize it. The current gain sum $\alpha_{npn} + \alpha_{pnp}$ rises quickly with current, permitting efficient switchback to a low voltage at a low current I_H. At this point, and for all higher currents, all three p-n junctions are forward biased, with the outside two of polarity opposite to the center junction. Hence, the total voltage drop across the device is approximately that of a single forward-biased silicon p-n junction, about 1 volt. Hold current I_H is typically in the range of 1 to 50 mA. For currents larger than I_H, the multiplication factor M is equal to unity because of the low voltage, so the equation describing this region is $\alpha_{npn} + \alpha_{pnp} = 1$.

The short section of the SCR V-I characteristic extending vertically from V_{BO}, Fig. 26, is present on some types made utilizing a "short-circuited junction" geometry—for example, in Fig. 25 (top), if the cathode contact were to extend a short distance farther to the right, it would short-circuit a section of the upper p-n junction on the surface. As V_{BO} is exceeded, appreciable avalanche current from the center junction flows through the short-circuited region into the cathode instead of having to flow through the upper p-n junction. Hence, the effective emitter efficiency of the upper (n-p-n) transistor is zero. As current is increased, however, lateral current flow through the upper p-type region, Fig. 25 (top), produces a transverse voltage drop there, causing the left section of the upper p-n junction to receive a forward bias. This triggers the main p-n-p-n anode-to-cathode breakdown, which occurs somewhat away from the short-circuited region. The short-circuited junction geometry is built into an SCR structure to promote temperature stability of V_{BO}. An effect of this type may be obtained on nonshort-circuited units by attaching a resistor between gate and cathode; see Fig. 25 (top).

If the gate is given a small bias in a direction so that the upper p-n junction is forward biased, the upper three junctions behave as a transistor, and current flows. The current flow increases α_{npn} or α_{pnp} or both, and, if it is large enough (that is, of the order of I_H), the high-impedance region (Fig. 26) disappears. The characteristic then follows the short dashed curve from the origin to I_H. Hence, switching from A to B is accomplished by the application of sufficient gate current that the high impedance region is eliminated (or very much reduced) and point B becomes the only stable operating point available for the circuit. The device will stay at point B when the gate signal is removed.

For an anode–cathode potential of the opposite polarity, the two outer p-n junctions are reverse biased. Switching action does not occur in this case and the SCR behaves like two reverse-biased junctions in series and undergoes avalanche breakdown at the sum of their individual breakdown voltages. Silicon controlled rectifiers are generally rated (at 125°C) with the same values of forward and reverse breakdown voltages.

The silicon controlled rectifier has an advantage over power transistors when used for off–on switching. Since the action is regenerative and has two stable points (without the need for gate current), current flow is uniform over the area of the device, except for small perturbations in short-circuited junction structures. No crowding toward a junction periphery takes place. Hence, simple large-area geometries suffice for very-high-current operation.

Gate-firing characteristics for an SCR must be well specified to make sure that all units of a given type will turn on if a gate pulse beyond a given current threshold is applied. Also, since the gate region—and usually the gate lead, too—is small compared to the anode and cathode, applied gate power must be limited.

The highest-current SCRs are rated up to 400 volts and lower-current units are generally rated in the 600–800 volt range. Newer devices show promise up to 1500 volts. The power controllable by a 400-volt 300-ampere unit approaches 100 kW, and can be reliably switched by the expenditure of as little as 1 watt. Thermal resistance from junction to case (stud) of a power SCR runs from 0.1 to 1°C per watt. Since the SCR is often used for controlled rectification, wherein the device is triggered to start conduction at a particular phase angle of a sinusoidal or square-wave power voltage, the units are generally graphically rated for the convenience of the user, so permissible average forward current is specified as a function of conduction angle. Most silicon controlled rectifiers are rated for operation up to 125°C.

If the duration of a high-power pulse is short compared to the thermal time constant of the heat-removal system, the user can take advantage of a much lower thermal resistance, since thermal gradients are higher. Thus, L in Eq. (4) is effectively shortened. Turn-on times for an SCR are short because of the regenerative nature of their switching. Even the larger units turn on in about 1 μs. If anode–cathode voltage is applied too quickly (for example, when controlling conduction in a square-wave system), however, the value of V_{BO} may be lowered. This dv/dt effect occurs if the charge released from the center junction when it is quickly reverse biased is sufficient to charge up the bases of n-p-n and p-n-p component transistors. The effect is most severe if the central n-type and p-type regions are thin. High-power SCRs have relatively thick regions, however, and voltage application rates of greater than 10 volts per μs are generally permitted without lowering V_{BO}.

The turnoff time of an SCR is much slower than the turn-on time, and is circuit dependent. Most devices are rated through 400 c/s sinusoidal and square-wave operation, with newer (medium current) SCRs operable above 10 kc/s. Turnoff is quickened if reverse anode–cathode voltage is applied. Even though the anode–cathode current has dropped to a value below I_H, the SCR may refire at a voltage below V_{BO} if sufficient time has not been allowed for recombination of charge stored deep within the device. Hence, turnoff time must be measured by determining how long a time must elapse before a voltage of V_{BO} is required to fire the unit.

For certain pulse applications, switching is entirely within the first quadrant (Fig. 26). A high reverse-voltage rating is not required. Silicon controlled rectifiers of this type are rated to close to 1000 volts V_{BO}, 100 amperes repetitive (10 μs) pulse current. Turn-on times are in the range of 250 nanoseconds. Turnoff times (with 10 amperes reverse current) are several microseconds. Forward-voltage application rates exceed 50 volts per μs.

The silicon gate-controlled switch (GCS) is an SCR in which the gate can be used to turn the unit off as well as on. Consider a controlled rectifier to be on (position B in Fig. 26). A reverse bias on the gate will change the characteristic to that shown by the long dashed line (if the SCR does not burn out first). The only stable point for the anode–cathode bias circuit is at A, so the device must turn off. Gate control works by robbing the upper transistor of some of its minority-carrier base charge. Hence, a higher current is required to make $\alpha_{npn} + \alpha_{pnp} = 1$, and I_H moves up to I_H'. The gate electrode must obtain at least partial control over the base region it contacts, and thus the situation is between that of an SCR and a transistor.

Silicon gate-controlled switches are rated up to 400 volts, 5 amperes. They turn on with forward gate currents similar to those of an equivalent SCR, but have less gain during turnoff. For example, turnoff from 5 amperes to 25 volts is accomplished with 500-mA reverse gate current, or a turnoff gain of 10. This is lowered at higher voltages and lower currents, as shown in Fig. 27. Ratings are for a 200-μs pulse width. The GCS can simplify switching circuitry, as shown in Fig. 28, for an electronic ignition system.

The silicon GCS is a recent product innovation, and

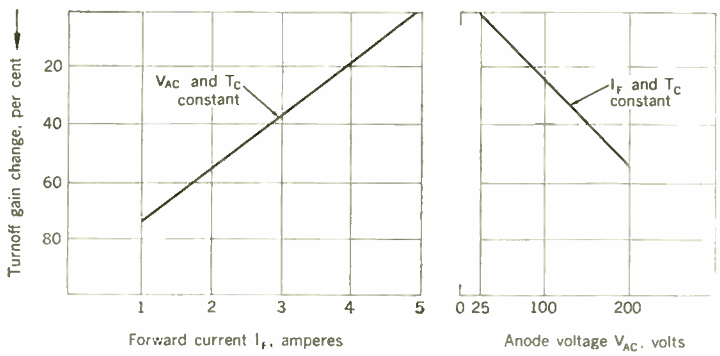
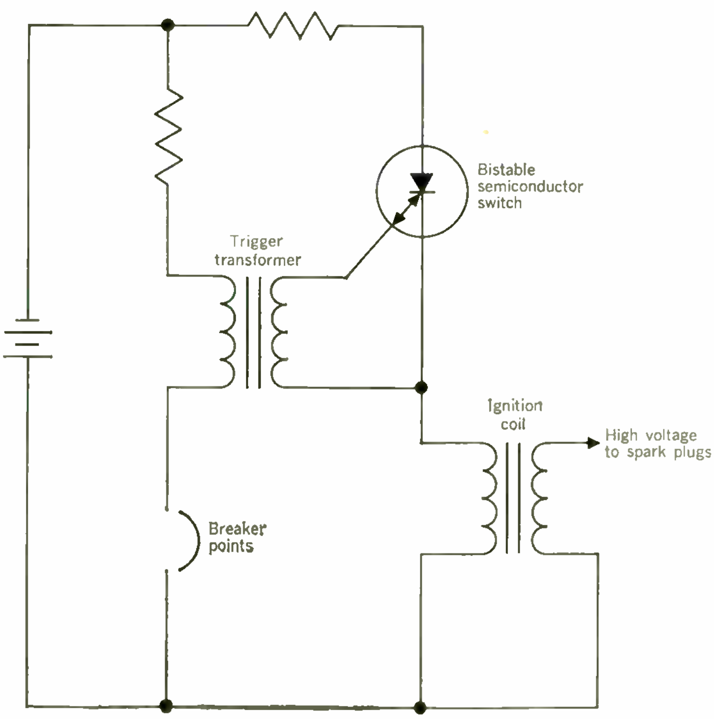


Fig. 27. Change in turnoff gain for a silicon gate-controlled switch with current and voltage. T_C (temperature of case) is held constant for these curves and produces a small effect (about 20 per cent) from —40 to 100°C

Fig. 28. Simple electronic ignition system utilizing a bistable semiconductor switch (silicon gate-controlled switch)



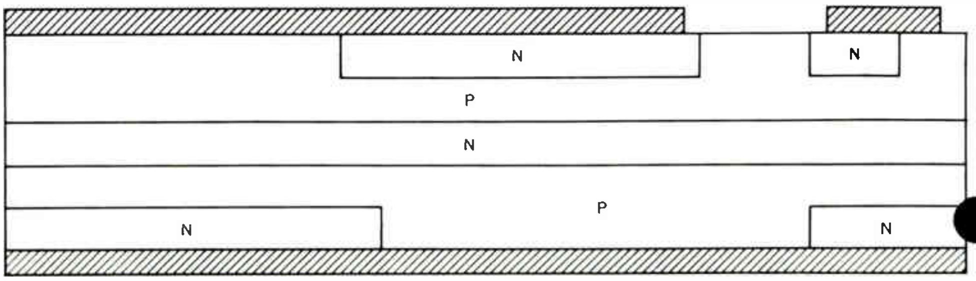


Fig. 29. Internal geometry for a silicon controlled rectifier that may be turned on by pulses of either polarity applied to gate (small upper electrode) for either polarity of potential between main (large) electrodes

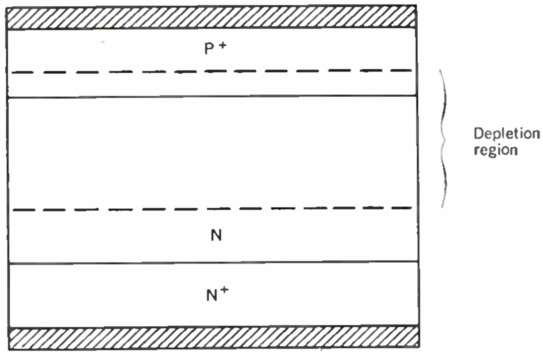


Fig. 30. Schematic representation of a p-n junction depletion region

should witness rapid improvement in characteristics, particularly in current rating and turnoff gain. Other more complex structures have been demonstrated in the laboratory and should appear as products in the near future. These include a five-layer diode—that is, n-p-n-p-n with double short-circuited junctions—for symmetrical two-terminal switching, and a three-terminal five-layer device that is switched on for either polarity of anode–cathode potential by means of a pulse of either polarity applied to the gate. Fig. 29 (after F. E. Gentry, General Electric Company) illustrates the rather complex internal geometry of the latter device.

Power varactors

The varactor is a p-n junction rectifier designed to maximize junction capacitance variation with voltage and to minimize series resistance. For high power capability, high reverse breakdown is also necessary. Because of its nonlinear properties, the varactor is used to generate higher harmonics from a signal impressed across it. *V-I* characteristics of a varactor are like those for any p-n junction (Fig. 1).

The depletion region that defines the extent of a p-n junction is illustrated in Fig. 30. It is a region which, to a first approximation, contains no mobile charge, but contains a large fixed charge. Hence, its behavior is much like that of a parallel-plate capacitor, and

$$C = \frac{\epsilon}{w} \qquad (19)$$

where

C = capacitance per unit area
ϵ = dielectric constant (12 for silicon)
w = width of depletion region

The value of w depends upon the total potential across the depletion region, increasing for reverse bias and approaching zero for large forward bias. An applied po-

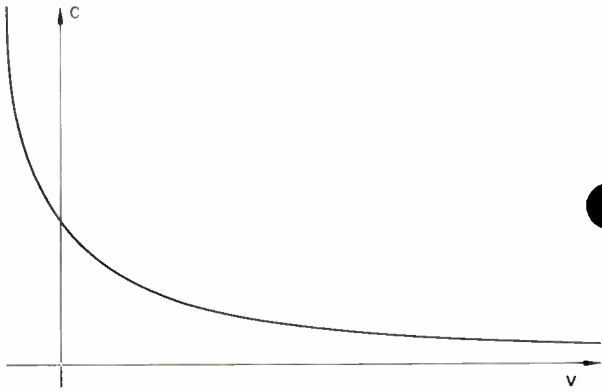


Fig. 31. Capacitance vs. voltage for a p-n junction varactor

tential appears, to a first approximation, entirely across the depletion region, adding to (reverse bias) or subtracting from (forward bias) the built-in junction potential Φ—in the range of 0.7 volt for many silicon p-n junctions.

For an abrupt p-n junction

$$C_j \propto (\Phi - v)^{-1/2} \qquad (20)$$

For a linearly graded p-n junction

$$C_j \propto (\Phi - v)^{-1/3} \qquad (21)$$

Powers from $-1/2$ to $-1/5$ are obtained in practice, depending in detail upon the impurity distribution in the structure. If the bottom edge of the depletion layer, Fig. 30, should reach the n+ boundary before avalanche break-

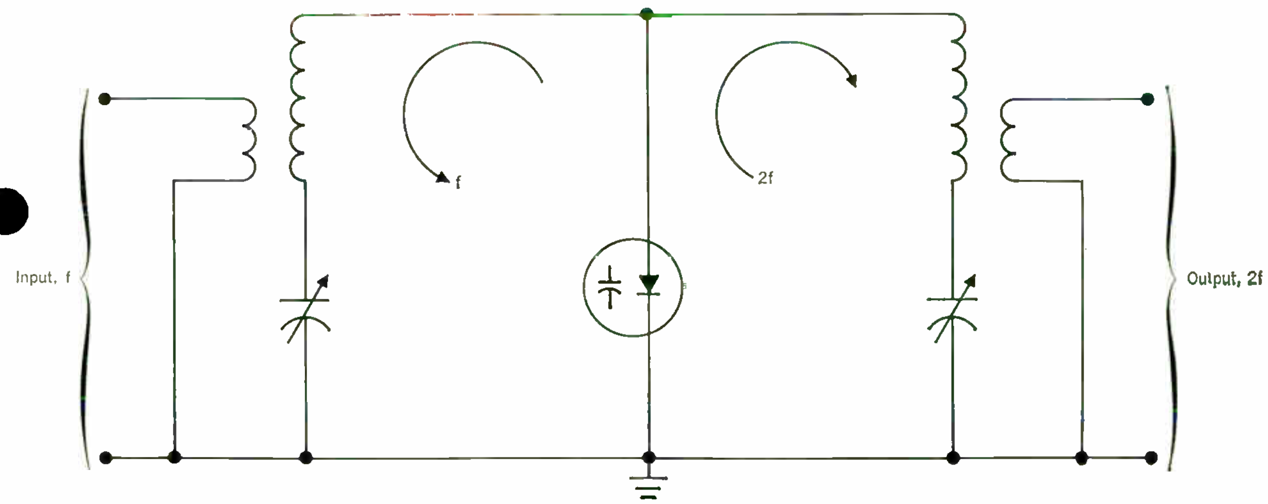


Fig. 32. Simple varactor frequency-doubler circuit

down, the extent of the depletion region w from that voltage until breakdown is almost constant, and so the capacitance changes very little with voltage, as seen in (19). Operation of a varactor under reverse bias is limited by the avalanche breakdown voltage V_B, shown in Fig. 1.

Under forward bias, appreciable quantities of holes are injected from the p^+ region into the n-type base (Fig. 30). These are neutralized by electrons, and can constitute a charge much greater than the free electron charge in the n-type material by itself. This charge lowers the effective resistivity of the n-type region, a fact that is responsible for the extremely high forward efficiency of a p-n junction rectifier. Since this large charge is stored by virtue of a forward junction voltage, it constitutes a capacitance called diffusion capacitance, in addition to and effectively in parallel with the junction depletion region capacitance. Hence, as the p-n junction goes into forward bias, its capacitance increases at an extremely fast rate because both the depletion capacitance—as $v \rightarrow \Phi$ in Eq. (20)—and diffusion capacitance terms become large. A plot of total capacitance versus voltage for a p-n junction varactor is illustrated in Fig. 31.

A p-n junction varactor may be considered to be a nonlinear capacitor $C(V)$ with a series resistance R_S. If a sinusoidal current is impressed upon a nonlinear capacitor, of the type indicated in (20) or (21), the voltage appearing across the capacitor will be nonsinusoidal. It will contain harmonics of the fundamental signal. In a practical case, the current, voltage, and stored charge will all be nonsinusoidal functions of time. When the nonlinear capacitor is placed in a circuit so that it is common to loops resonant at fundamental (input) and first-harmonic (output) frequencies, much of the input signal at frequency f is converted to frequency $2f$. Figure 32 shows a simple frequency-doubler circuit.

The efficiency of frequency conversion by a varactor is a function of the losses in the system. The circuit Q, which is important, is controlled to a large extent by the quality factor Q of the varactor diode.

$$Q = \frac{1}{2\pi f R_S C} \qquad (22)$$

A diode cutoff frequency f_c is defined as the frequency at which $Q = 1$, so

$$f_c = \frac{1}{2\pi R_S C} \qquad (23)$$

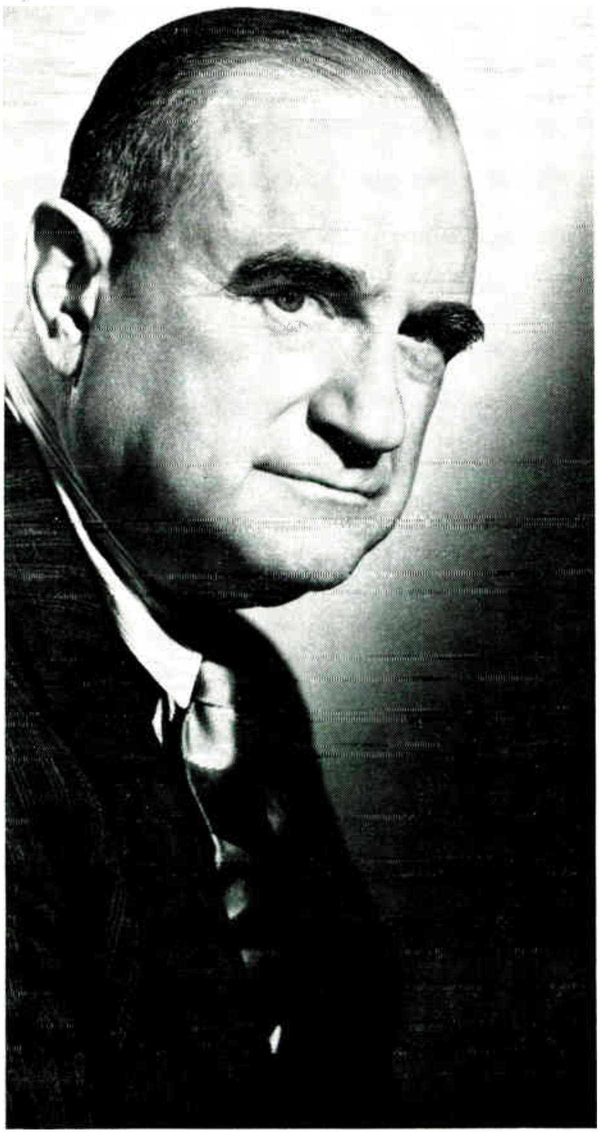
R_S and C both vary with voltage. For a good 25-watt silicon varactor, C will be in the range of 50 pF (measured at 6 volts reverse bias). R_S climbs from about 0.5 ohm at 300 volts reverse bias to several ohms as zero bias is approached. This gives a device Q of well over 100 for most of this voltage range, and a cutoff frequency f_c at 300 volts approaching 50 Gc/s, and at 6 volts of about 2 Gc/s. Equations (22) and (23) are only partially realistic, however, since they do not take into account how much C varies with voltage.

Advantage can be taken of the very wide capacitance swing under forward bias at high frequencies by proper circuit biasing. If a diode is driven into forward bias under low-frequency conditions, current flows and Q is very much lowered. If the diode is driven into forward bias for part of a high-frequency cycle, however, the injected charge can be extracted as the junction swings quickly into reverse bias. Hence, there is little loss since almost no ohmic current flows. By the use of these techniques, as well as by careful circuit tuning, varactors are presently capable of accepting 50 watts input at 50 Mc/s and doubling frequency at greater than 80 per cent efficiency or quadrupling at over 40 per cent efficiency.

Strings of varactor multiplier circuits are used to take power from the 50-Mc/s range and convert it with reasonable efficiency to well beyond 10 Gc/s. Figure 23 shows how the use of varactors for frequency multiplication has extended the range of transistors. Because of the extremely nonlinear operation of varactors, their performance is very difficult to calculate and circuit tuning is extremely sensitive. Nevertheless, their use above 100 Mc/s is important at the present time and will continue to grow. From the device standpoint, decreasing R_S is the most important problem. Linearly graded silicon structures offer an advantage in this respect. Also, germanium and gallium arsenide, because of their higher mobilities, may find widespread use above 1 Gc/s.

IEEE spectrum—Retrospect and prospect

Alfred N. Goldsmith *Editor Emeritus and Director Emeritus, IEEE*



Eighty years ago a great society of electrical engineers was born. At that time its planners laid heavy emphasis on the communications aspects of electrical engineering. At first they stressed telegraphy, and later telephony as well. Then, with greatly expanded activities, the American Institute of Electrical Engineers took its place as a worthy representative and tool of the electrical branch of the engineering professions.

Twenty-eight years later there came into being another major engineering society specializing strongly in two particular divisions of electrical engineering—communications and electronics. This organization, The Institute of Radio Engineers, also prospered. And it too grew into a definite symbol and instrument of the professional engineering interests of its membership.

The coexistence of these two societies was, on the whole, gratifyingly dignified and peaceful. Yet it seemingly perpetuated an anomaly, which resulted from a partly artificial division of electrical engineering into two arbitrarily delimited sections. Although AIEE was also vigorously active in the electronics and communications field, IRE stressed comparatively few portions of most of the other divisions of electrical engineering. Inevitably there was undesirable duplication of effort by the two societies. And there was a corresponding partial waste of funds and, more important, of skilled and relatively scarce engineering manpower.

The problem of unity

Four decades ago the need for unity in the electrical engineering profession became increasingly evident, at least to some of us. But formidable obstacles loomed in the path to unification. These included the jealously guarded corporate standing of the societies, the personal pride or individual ambitions of important members, resistance to supposed subordination of one society or the other, outright conservatism, and normal competitive instincts. These factors and other all-too-human elements for many years were solid roadblocks in the path of the merger of the two Institutes.

Yet the wheel of time turned irresistibly from a partly unsatisfying past toward a brighter and greater future. Increasing tolerance and understanding sprang up between the societies—first as tender shoots, then as massive-trunked and sheltering trees. Mutual understanding led to growing cooperation. The need for unification became ever clearer. Accordingly, when a comprehensive merger proposal, painstakingly developed, was submitted in 1962 to the AIEE and IRE memberships, it was accepted by an overwhelmingly favorable vote. And now we, the membership of the older societies, *are* The Institute of Electrical and Electronics Engineers, Inc. And we have in our hands all the responsibilities and challenging opportunities conferred in our new corporate charter.

Thus, with broad coverage of the entire electrical and electronics field within our scope, it is appropriate that IEEE should select as its unifying and "core" publication, reaching all its members, a new journal born this month—fittingly termed IEEE SPECTRUM. Its novel designation was wisely and felicitously suggested by E. K. Gannett, in charge of IEEE Editorial Operations, and W. R. Crone, Consultant to the IEEE STUDENT JOURNAL.

It is anticipated that IEEE SPECTRUM will contain review and tutorial articles, and occasionally articles of broad and fundamental import. It will include articles of application and of economic significance. It will present news of the profession and of IEEE, announcements and reports of conferences and conventions, news of education, and letters to the editor on topics of broad concern as well as of general interest. Also included will be news of scientific and engineering advancement, items of political and social interest to the profession, and abstracts of or references to material in other IEEE publications. The technical level of IEEE SPECTRUM will be such that it will be a positive force in upgrading the level of membership ability and in fostering the development and expansion of the field encompassed by IEEE. It will inherently aim to be an agent for human progress through enhanced professional capabilities.

The title IEEE SPECTRUM is particularly appropriate in view of the unusually wide range of topics falling within the scope of IEEE. These subjects, at present, might include (merely as a small and typical sample): electrical applications of Boolean logic and algebra, error-correcting codes, magnetohydrodynamic power generators, peak-power storage in elevated water basins (tidal or artificial), helicopter placement of transmission-line towers, fuel cells as primary generators, magnetic memories of the ferrite-core or thin-sheet types, status of electronic prosthetic devices in medicine, plasma absorption of electromagnetic radiation from re-entering space vehicles, and space communication over tens or hundreds of megamiles. One might multiply this sample many hundredfold to acquire some concept of the breadth of knowledge that will necessarily be presented in IEEE SPECTRUM.

Professionalism

Yet, serving as a source of dependable and timely information on matters within the scope of IEEE, and thus keeping the membership of the Institute up to date in its fields, is only one of the purposes of IEEE SPECTRUM. Another primary aim of IEEE and its publications is to foster and strengthen the professional standing of its members and to promote and emphasize their professional accomplishments. It is appropriate here to consider briefly the nature of professionalism and the personal value and significance of the professional attitude among engineers. Our new publication, IEEE SPECTRUM, will appear in clear perspective if its aims are shown to be definitely identical with those of IEEE itself. Publisher and publication must be parts of the same consistent and coherent structure. Accordingly it is fitting here to consider the nature of the professional engineer and of his chosen implement, our Institute. Thus the services rendered by IEEE SPECTRUM will be clearly seen and justified.

There is of course a close professional kinship between electrical and electronics engineering and the older professional fields. Technically considered, the closest relationship is probably between the field of the IEEE and the civil and mechanical engineering fields. Ethically and socially, the field of IEEE perhaps seems closest to the field of medicine. Professional consulting engineering calls for the solution of individual problems somewhat similar to those encountered in electrical and electronics engineering and involves the acceptance of similar ethical concepts. The legal profession is based on somewhat different fundamental needs and concepts. Yet it and the field encompassed by IEEE are slowly approaching similar common bases and modes of attack on problems.

Professionalism merits a clear definition. To avoid confusion, we should first consider some elements that, though not directly within the purview of a learned society such as IEEE, are self-evident requirements for the successful functioning of the professional man. To begin with, these are the establishment and maintenance of reasonably attractive working conditions and adequate remuneration for the engineer, permitting personal and family life at a cultural level. Included are due public and private recognition of the value of the work of the individual engineer (even though the engineer has not been notable as a seeker for fame through self-advertising which, in fact, is viewed with doubt or distaste by most ethical engineers). The preceding factors must be regarded as the necessary socioeconomic foundations of any healthy professionalism.

But at this point we must face a group of complex, knotty, and potentially controversial elements involved in professionalism. We must ask ourselves such questions as: What are the essential elements of a professional calling? How do they differ from those of a trade or a craft? What are the inherent obligations of a professional worker? How shall his fellow workers and the public recognize his unique characteristics and accomplishments?

The usual dictionary definitions are not particularly helpful in attempting to answer these questions. Thus, a profession is defined as "the occupation, if not commercial, mechanical, agricultural, or the like, to which one devotes oneself." A craft is defined as "an occupation requiring art or skill." The definition of a trade is, for example, "a means of livelihood" or, alternatively, "the act or business of exchanging commodities by barter or sale."

Admittedly, different men might give diverse answers to the questions posed above. Yet it is believed that the nucleus of agreement, like the nucleus of the atom, is firmly knit and adequately definable. Here, then, are some proposed answers to these questions. The inherent factors in a professional occupation include the possession of a wide range of knowledge, both broad and detailed, of the chosen field. Also needed is much more than a smattering of its relation to society in general, implying as well a good understanding of the humanities. Other factors are the possession of unusual skills in applying the teachings of the field, a strong sense of responsibility and of personal dignity, and a measured pride of accomplishment in the field. These factors lead naturally not only to self-respect but also to respect for fellow workers. They require a firm refusal to engage in comment or conduct prejudicial to a comember in the field unless clear ethical considerations, violations of law, or obvious neglect of duties lead to a public controversy or a legal procedure in which professional men must be involved.

Thus the obligations of the professional worker flow naturally from his standing and privileges. His main objects in life are such as to emphasize and justify his special repute, his scientific and technical skill, his creativity, his social importance to humanity, his ethical guidance, and his intraprofessional relationships.

IEEE fits well into this matrix of purposes. Clearly one of its major functions is to nurture and preserve a precious dichotomy. This dualism involves the reconciliation and coexistence of the socioeconomic elements and the professional aspects of the electrical engineering profession. As has been stated, one part of the engineer's life is not dissimilar to that of other men. It is obviously essential that the engineer and his family shall live an economically pleasing life free from harassment or distress arising from his daily needs and the development of his long-term security. An atmosphere of acceptable peace and modest plenty are rightfully needed. To these ends the engineer, as an economic unit, rightfully asks an adequate scale of remuneration and a congenial type of environment. Sometimes the engineer handles these matters directly through personal negotiations. And sometimes these factors are worked out by group association and large-scale negotiation. But, in any case, their handling is a necessary and normal part of the engineer's life.

But man lives not by bread alone. The engineer is first and foremost a professional man. What then shall we seek as a primary function of IEEE? Clearly, one such aim must be firmly to establish and maintain professionalism under the guardianship of IEEE. If we succeed in building up IEEE as the vigilant and effective symbol of engineering professionalism—and we shall—all else may well be given to us.

Yet there are many matters of detail that must be considered. As influential and large an organization as the IEEE is justified in taking a "long, hard look" at its purposes, procedures, and accomplishments, and even at its daily activities. Great amounts of human effort, time, and devotion have gone and will go into IEEE. Correspondingly convincing and decisive reasons justifying its aims, its mode of operation, and its desired results can legitimately be sought and developed with utmost care.

Without any wish to be dogmatic or didactic, here are some personal concepts concerning this Institute, which belongs to all of us. Considering its specific aims, these concepts clearly include the orderly large-scale collection and dissemination of comprehensive and advanced information in the electrical and electronics field. This information should range from the most specific to the most general; from the longest-term historical data to the latest "news of the minute"; and from the most highly technical data through humanitarian aspects of public interest to the study of the particular needs and personal welfare of the members of our Institute. Every available and logical agency for the collection of information should be considered and, if found suitable, should be effectively utilized. And all available and powerful modes of dissemination of the gathered information should be used, including small specialized meetings, larger meetings, conventions, world conferences, publications, and wide distribution of films and tapes.

Since IEEE is a nonnational body, it must appropriately proceed on the valid basis that science and engineering know no frontiers. Truth has a scope as wide as the cosmos. To implement so broad a plan, great care must be taken to encourage and support activities of IEEE in every country of the world. The IEEE membership in each country must enjoy in equitable measure every opportunity and privilege granted to those in other countries. Race, creed, and national origin are not relevant factors in the standing and advantages to be enjoyed by every member.

It follows naturally that each body of regional members shall have full opportunity to work out its problems, to exercise its organizational and administrative ingenuity, to expand its Sections and Chapters in healthy fashion, and to make its maximum contribution to the fulfillment of the general aims of IEEE.

Some interesting, difficult, and challenging problems are therefore encountered by a nonnational body like this Institute. One of these is the barrier of language differences. Here an early and complete solution may be economically impracticable. However, several steps toward making all technical material issued by IEEE equally available to all or most members (and readers) are possible. Various fields must be explored, openmindedly. These include multilingual editions (or abstracts) and utilization of machine-translation facilities, with the resulting availability of printed, microfilm, or tape versions of basic material. The ultimate aim is to make every technical advance in the field of the Institute available to all.

Members' needs and obligations

At all times, the needs of the membership and of the community should be kept in mind as guides to preferred procedures. These activities of the Institute, its Sections, Regions, Chapters, Professional Technical Groups, Committees, and other Divisions should be skillfully and painstakingly adapted, probably on a partially pragmatic or even empirical basis, to the needs of the membership and to the benefit of the public.

IEEE has acquired a rich heritage of accomplishments from its parent societies. The professional assets of IEEE represent in considerable measure the summation of the achievements of AIEE and IRE. These accomplishments are so outstanding and helpful to IEEE that nothing further need be said on the subject. As to the future, however, even more may confidently be expected from IEEE. It must be expected to accomplish many and more complex tasks. Scientific and technical progress in its field must be progressively and systematically promoted. The professional viewpoint and standing of the Institute and its membership must be jealously guarded. The public must ever be made aware that the engineer members of the Institute are not only the dependable custodians of profound knowledge, skill, and creativity but also the exponents of the high and demanding standards of professionalism. The dignity and importance of the electrical and electronics field must continually be explained and stressed.

In the light of these needs, it is seen that there are definite obligations involved in IEEE membership. Each member should feel a proper pride in his Institute and should do his utmost to enhance its standing. There is an urgent need for the maximum of "grass roots" activities. Only thus can the Institute continue to enjoy democratic regimes, consistent with firm and capable everyday administration. Each member may well have a group of unified loyalties, which are different aspects of the same basic identification of himself with his Institute. A man may be a dweller in his home town, a citizen of his local state or regime, and a citizen of a nation. So too an IEEE member may be a member of his local Section and Chapter, a member of his Professional Technical Groups, and a member of IEEE. These multiple affiliations are all different aspects of the same association. Together they form the strong bond between IEEE members, imbued with a common purpose, and their Institute.

Despite the most careful planning and an enthusiastic membership, the path of IEEE may nevertheless be beset with pitfalls that must be carefully avoided. There may well arise a trend toward bureaucracy, with its cumbersome, costly, and time-consuming frustrations. Attempts at "empire building" may arise, with their corresponding animosities and political overtones. Ill-advised members of industry or government may attempt to wrest control of IEEE policies and procedures from the members of the Institute, with consequent damage to the professional spirit of the Institute. There may arise deviations from high professional ideals and methods. And, last but not least, the prolonged maintenance of vestigial and useless customs may perpetuate a tragic waste. The membership of the Institute and its elected representatives and headquarters staff must be ever on guard against these insidious weaknesses, which could be encountered in the future of IEEE.

Perhaps one of the best panaceas for these ailments is the avoidance of any freezing of the form and activities of the IEEE. A dynamic future must consistently be sought. At every step, careful judgment based on experience must be exercised. Viewpoints must be kept flexible, perhaps through an empirical approach to many problems. And there must be an open-minded readiness to try out new plans, and modifications of old plans, whenever inadequacies in current principles of operation become evident.

In brief, the future success of IEEE will rest on the enterprise, originality of thought, and the loyalty and professional pride of its membership and their representatives. And always the independence of the Institute must be sedulously guarded so that it may fulfill the purposes for which it was established.

Prospects for the future

On the basis of these guiding principles, we may speculate optimistically as to the future of our IEEE. We may anticipate that it will render many and valuable services to us, its members, and that it will make important contributions to human welfare. We are called on to retain our enthusiasm, our inspiration, and our willingness to render yeoman service to our Institute and thus to each other and to society. If we do, a bright vista of accomplishment is spread before us.

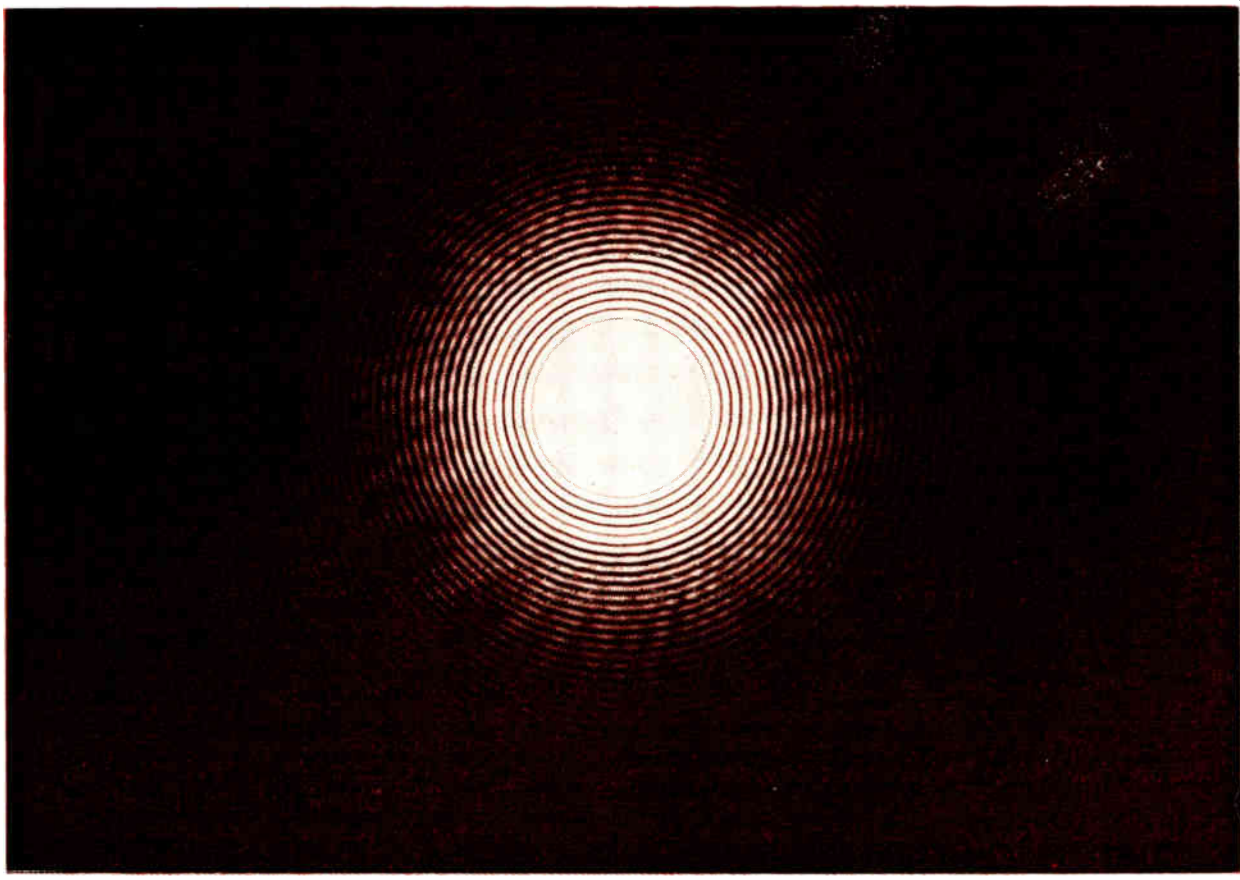
Never should it be forgotten that this IEEE is *our* Institute. It is no more and no less than a reflection of our hopes, our ideals, our professional dedication, and our sense of our value to each other and to the world. It is ours to mold, to change, to guide, and to re-create in an increasingly worthy form.

Each of us, therefore, is most fortunate in having the unique opportunity and the pleasant obligation of adding our quota to the integrated efforts of our IEEE membership. Thus our Institute will not be merely a large society; rather, it will be a great and admirable institution of social and professional worth. It will symbolize the professional aspirations and accomplishments of each of us, and of all of us together. And these, it is hoped and expected, will ever be ably reflected in our new journal, the IEEE SPECTRUM, which is now laid before us.

New coherent light diffraction techniques

Scattered coherent light exhibits a granular, sparkling appearance. Experiments described give an insight to this phenomenon. Diffraction techniques permit giant antenna scaling with desk-top scale models

Wright H. Huntley, Jr. *Stanford Electronics Laboratories*



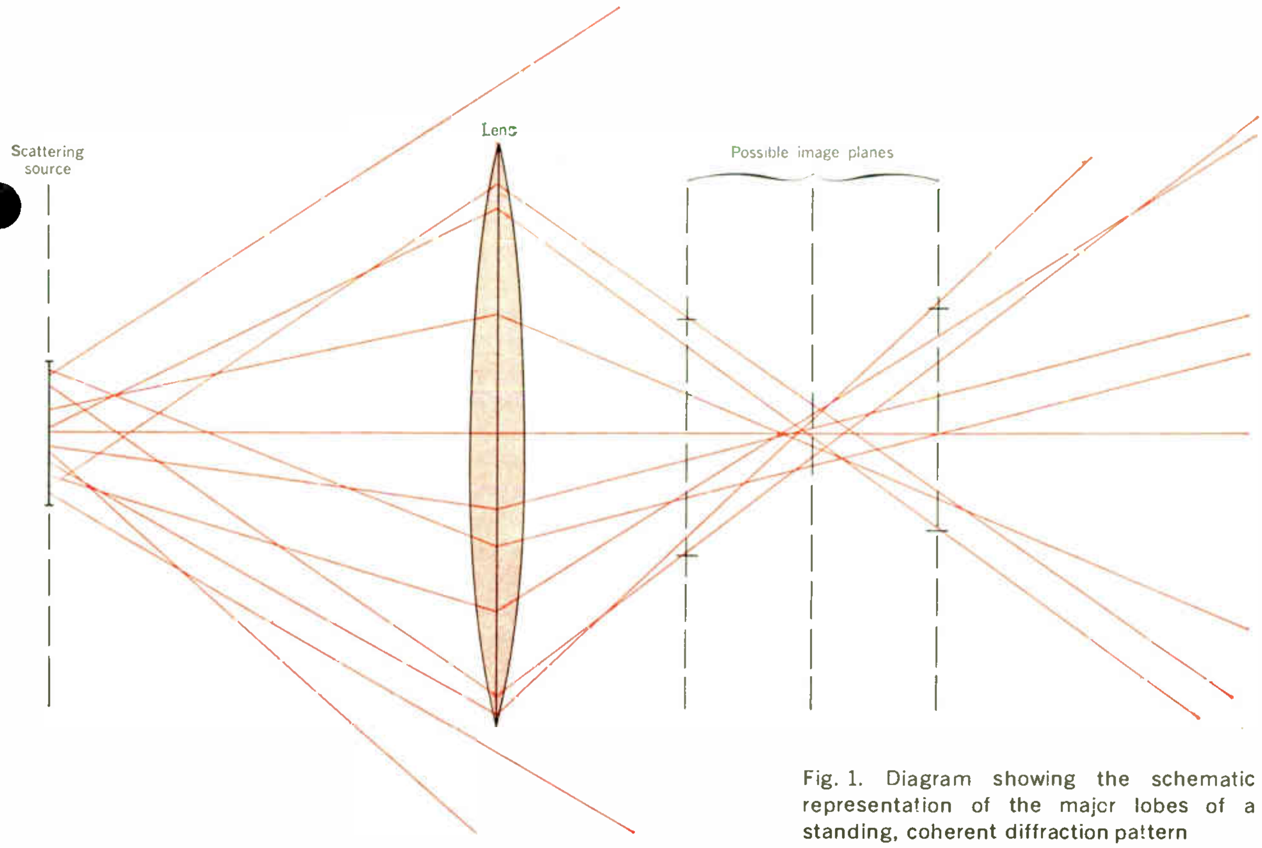


Fig. 1. Diagram showing the schematic representation of the major lobes of a standing, coherent diffraction pattern

When continuous-wave gaseous lasers are operated in the visible portion of the spectrum, an unusual effect is apparent to the observer. Wherever the beam strikes a scattering surface, the illuminated spot exhibits an extraordinary granular, sparkling appearance.

When examined at close range, the illuminated spot appears like a richly detailed mosaic and the viewer's first impression is that the laser must be oscillating in thousands of modes. This impression is readily disproved, however, when the observer moves his head from side to side; for the granular pattern does not remain fixed with respect to the scattering surface as one would expect with multimoding. Instead, it sweeps across the field of view. The relative direction of motion depends on whether the eye is focused in front or behind the viewing surface.

The best explanation of this phenomenon was given by B. M. Oliver,[1] who says that "... coherent light reflected by a diffusing surface produces a complex, random, but *stationary* diffraction pattern." He demonstrates that this pattern consists of a large number of needle-like beams which are essentially the lobes of the far-field radiation pattern of the scattering spot. Langmuir[2] has indicated the similarity between this standing pattern and the familiar problem of radar clutter wherein the sea, chaff, or moving trees give a fluctuating return; yet a similar pattern is involved. The pattern is simply more stationary with coherent light scattering because individual scattering points tend to maintain a fixed relationship to each other.

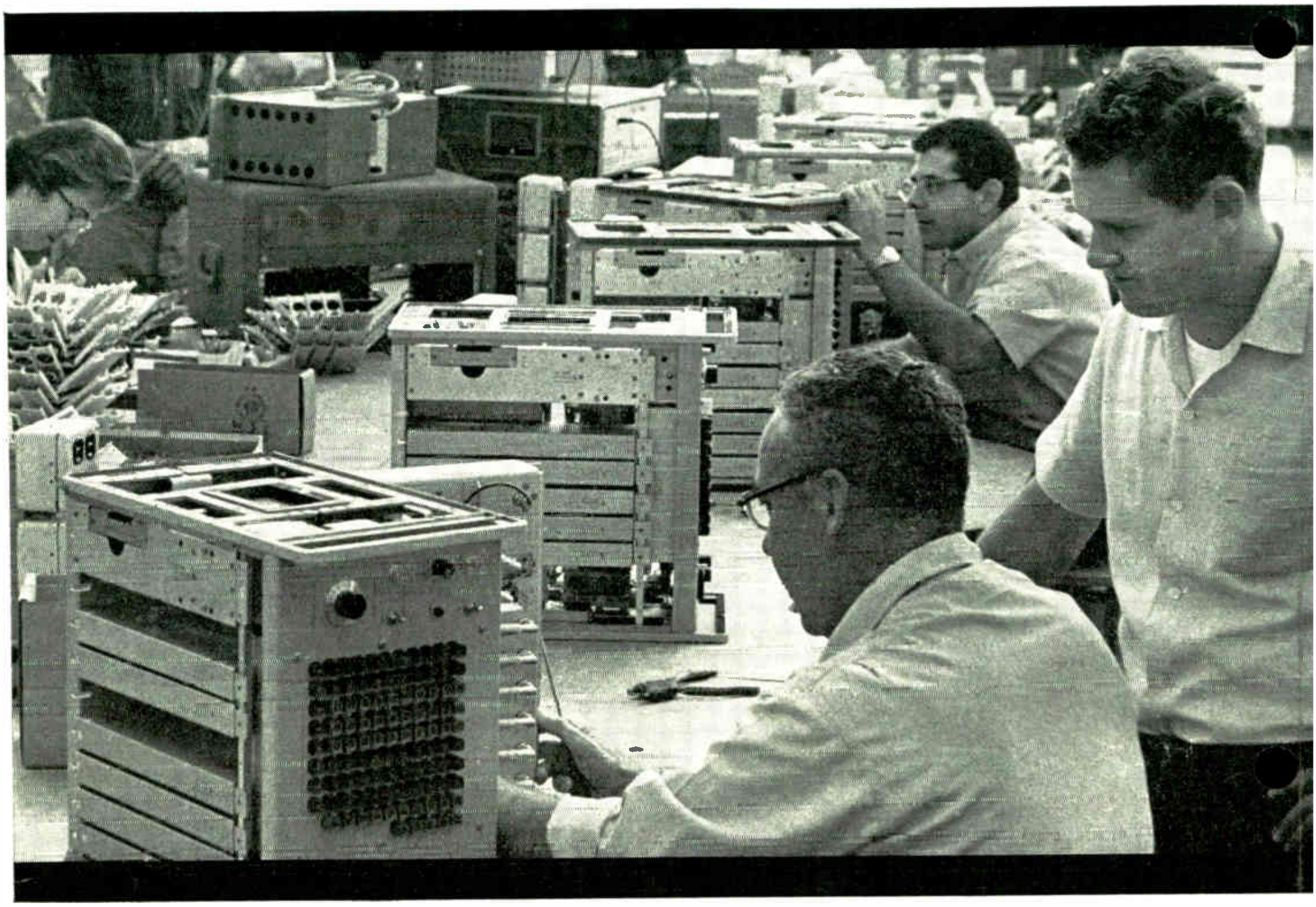
It is interesting that most people experience an odd psychophysical reaction when attempting to look at the scattering spot. If the spot is small—2 mm in diameter—and the observer is more than a few centimeters from the scattering surface, it is quite difficult to focus the eyes on the plane of the scattering surface. As a result, printing on that surface disappears (also described by Oliver). The reason for this illusion is that the stationary diffraction pattern exhibits granularity that always seems in focus, no matter where the eye is actually focused. Figure 1 illustrates the effect on the eye—or other imaging system—in the far field. Each line represents the center of one of the needle-like random lobes.

Focusing on the scattering surface produces an image of minimum size and the granularity is crowded into a small area. If the eye is out of focus, the over-all image expands and the details of the granularity are enlarged. Most observers find that their eyes focus automatically at some average point which yields rich granular detail and sufficiently small image size to have moderate intensity in the individual grains. This arbitrary focal plane almost never will coincide with the scattering surface.

Another effect can be seen from Fig. 1. If an iris is

Diffraction pattern obtained when a 6328-Å helium-neon laser beam passes through a pinhole onto camera film. The color red is matched as closely as possible to the actual color of the continuous-wave gaseous laser

hp FREQUENCY SYNTHESIZER PROVIDES 5 BILLION PROGRAMMABLE FREQUENCIES



Discrete signals, dc to 50 mc

Remote programming—1 msec switching speed

Frequency increments as small as 0.01 cps, as large as 10 mc

High stability and spectral purity—spurious signals 90 db down

high resolution, rapid selection

The new hp 5100A-5110A Frequency Synthesizer offers pushbutton convenience for fast, accurate selection of frequencies from 0.01 cps to 50 mc in steps as fine as 0.01 cps. Remote programming in less than 1 millisecond may be accomplished by external electronic switching. The excellent spectral purity is evidenced by the fact that spurious components are more than 90 db down (including power line components) and signal to phase noise ratio is greater than 60 db.

The system consists of the 5100A Frequency Synthesizer and the 5110A Synthesizer Driver. The latter contains a 1 mc quartz crystal oscillator which has a long term stability of ± 3 parts in 10^9 per day. The design of the instrument allows for the use of an external 1 mc or 5 mc oscillator. In any case, the output frequencies retain the accuracy of the chosen driving standard. The 5110A Synthesizer Driver generates twenty-two discrete, spectrally pure signals from the single standard frequency. These fixed frequencies are then fed to as many as four 5100A's by means of rear panel BNC connectors.

Manual frequency selection is accomplished by means of ten columns of pushbuttons arranged in standard decimal notation. Remote programming connections are made through three 50-pin connectors located on the rear of the 5100A. Further versatility in control is added by the fact that it is possible to use a combination of local and remote programming.

Standard instrument design provides a search oscillator which may be used in any one of the eight least significant digit columns. This technique allows the output frequency to be varied smoothly over the range of frequencies covered by the substituted column, either manually or by applying an external voltage.

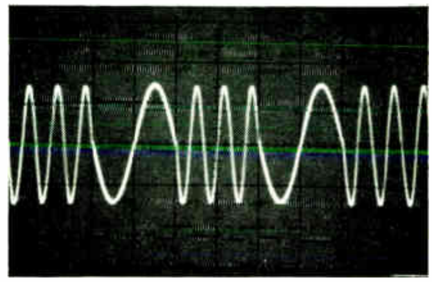
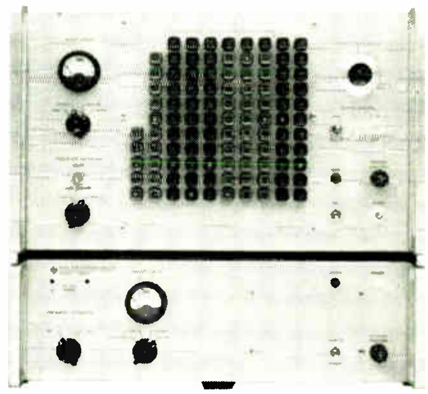


Photo shows rapid frequency switching capability of hp Synthesizer. In this application, Model 5100A-5110A is remotely switched between 1 kc and 3 kc at a 1 kc rate. Sweep speed is 0.5 ms/cm.



HEWLETT-PACKARD COMPANY

An extra measure of quality

1501 Page Mill Road, Palo Alto, Calif. 94304, (415) 326-7000. Sales and service in all principal areas. Europe, Hewlett-Packard S.A., 54 Route des Acacias, Geneva, Switzerland; Canada, Hewlett-Packard (Canada) Ltd., 8270 Mayrand St., Montreal, Que.

8435R

SPECIFICATIONS

Output frequency:	0.01 cps to 50 mc
Digital frequency selection:	From 0.01 cps per step to 10 mc per step; selection is by front panel pushbutton or by remote contact closure
Spurious signals and harmonic distortion:	All non-harmonically related signals are more than 90 db below (including power line components) the selected frequency; harmonics are more than 30 db below the fundamental
Signal-to-phase-noise ratio:	More than 60 db down in a 3 kc band centered on the signal
Frequency stability and accuracy:	With internal standard, less than ± 3 parts in 10^9 per day; with external standard, same as external standard
Output voltage:	1 v rms ± 1 db from 100 kc to 50 mc; 1 v rms + 2 db − 4 db from 50 cps to 100 kc into 50-ohm resistive load
Output impedance:	50 ohms nominal

Search oscillator:	Allows continuously variable frequency selection with an incremental range of 0.1 cps up to 1 mc, depending on the digit position being searched; dial accuracy is ± 3% of full scale; linearity with external voltage control is within ± 5% (−1 to −11 volts)
External standard input:	1 or 5 mc, 0.2 v rms minimum, 5 v maximum across 500 ohms; purity of output signal will be determined partially by purity of external standard
Interference:	Complies with MIL-I-16910A (SHIPS)
Temperature range:	0 to + 55° C
Dimensions:	5100A, 10¾" high, 16¾" wide, 16⅜" deep behind panel; 5110A, 5½" high, 16¾" wide, 16⅜" deep behind panel; hardware furnished for quick conversion to rack mount
Weight:	5100A, net 75 lbs.; 5110A, net 52 lbs.
Price:	5100A, $10,250; 5110A, $5,000

Data subject to change without notice. Prices f.o.b. factory.

placed ahead of the lens, the outermost lobes will be intercepted, the detail in the granularity will be reduced, and the eye will refocus to find a new brightness-detail balance. It is this automatic readjustment that causes the apparent increase in granule size when the scattering spot is viewed through a limiting iris. This effect is best examined on the ground-glass screen of a camera, where the aperture and the focus are independently controllable.

Observed effects and photographic investigation have all strongly established the validity of Oliver's hypothesis. This unexpected effect may have a major influence upon systems design. We might ask: What happens if the detector of a coherent-light radar falls in a null of the scattered return? What happens if the target moves? Can this effect be utilized in a system design?

Because these questions seem to deserve early answers, an effort has been made to demonstrate conclusively the validity of Oliver's hypothesis by repeating (with minor variations) his experiment and by devising new tests, and to extrapolate the results of this effort to indicate areas for future investigation and the application to possible systems.

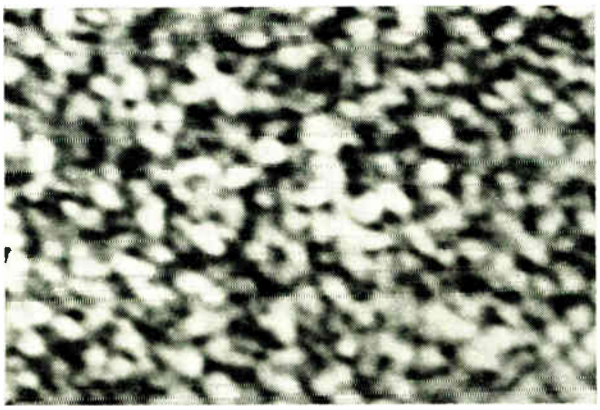


Fig. 2. B. M. Oliver's original photograph of the standing diffraction pattern

Fig. 3. Duplication of Oliver's photograph, except that transmission rather than scattering diffraction is used. (Difference in grain size is caused by dissimilar degree of enlargement)

Random-scatter experiments

Oliver's original photograph (Fig. 2) was taken by exposing the film to the scattering spot without lens or limiting aperture. An earlier assumption, attributing the granularity entirely to diffraction limiting in the incident beam, caused some confusion.

The photograph, reproduced as Fig. 3, was made by exposing the film as in Oliver's experiment but the spot was illuminated from behind the diffusing screen. That is, the laser beam illuminated the rear of a thick piece of white paper and the photograph is the result of the standing diffraction pattern produced after the light had diffused through to the surface nearest the film. However, the "diffraction-limited" argument is not entirely invalid. It merely tends to distract the casual reader from the more basic issue—that the source must be spatially stable for the diffraction pattern to "stand still."

While this first experiment indicated clearly that there was a stationary, standing diffraction pattern in space, an additional test was made to demonstrate that the only effect of an iris is to restrict the amount of the pattern reaching the film.

Figure 4 shows the results obtained when limiting apertures of various sizes are placed between the scattering surface and the film. As in the first experiment, no lens was used and the granularity is caused by light passing directly from the white paper to the film. Note that there is no difference in the granularity between (A) and (B). Only close examination reveals the slight effect of edge smearing from diffraction around the border of the iris.

The energy in any major lobe (bright spot) of the standing diffraction pattern is dependent upon net phase addition from incremental scattering points across the entire illuminated surface of the spot. It would be reasonable to expect that slight motion of the scattering surface in the laser beam would cause bright spots to dim, while other areas previously dark would become bright as new scattering surface is illuminated. Thus, one might expect the entire complex pattern shown in Figs. 2 through 4 to "boil" as the scatterer moves through the laser beam.

To confirm that this effect actually takes place, the paper was mounted on the minute hand of a clock, and the pattern was observed on the ground glass of a camera with no lens. The expected "boiling" did occur, but it was accompanied by an additional effect which should have been predicted. As usual, hindsight is exceptionally keen!

The unexpected effect was a large transverse motion of the pattern with respect to the amount of boiling. Since a small motion of the paper with reference to the incident beam diameter removes and adds only small scattering areas, it is possible for a given lobe to retain its identity while being swept through an angle which is very large compared to its diameter. This "sweeping" effect of the pattern is illustrated by the streaked appearance evident in Fig. 5. The photograph reproduced in Fig. 5 was taken with the same arrangement used for Fig. 4, but the scattering paper was moved very slightly with respect to the incident light beam during the exposure. Although Fig. 5 does not illustrate adequately

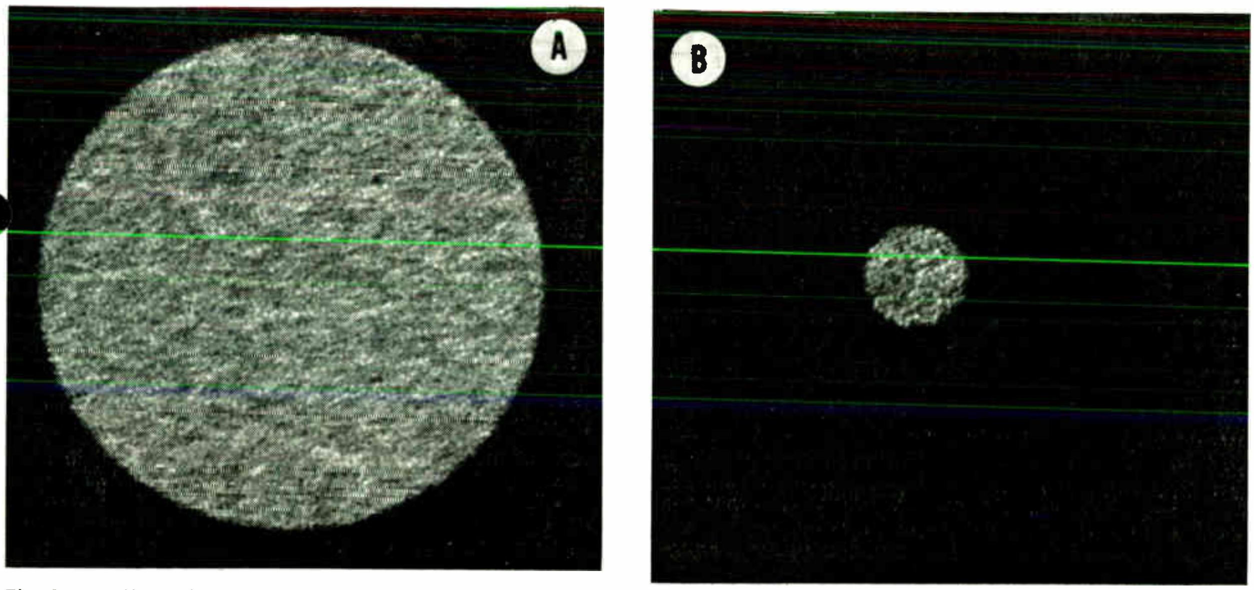
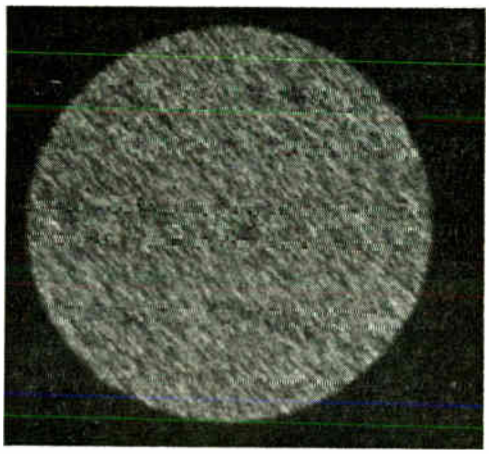


Fig. 4. A—Effect of an aperture between the scattering light and the film. B—Reduction of the aperture has no effect upon the granularity of the photograph image

Fig. 5. Streaking caused by motion of the scatterer in the laser beam is shown in this picture



the dynamic effect obtained by viewing the ground glass directly, it nevertheless does show the ease with which tangential motion of the scattering surface in the beam can be detected.

It appears from the results of this last experiment that the random scatter may have some useful applications. It was decided that the author's earlier assumption—that the granularity is always present in the image no matter where the optical system is focused (as indicated in Fig. 1)—should be verified.

Figures 6 (A) and 6 (B) were made with the use of a small telescope with a relatively large aperture in order to obtain sufficiently large images on the film. Figure 6 (A) shows the well-focused image of a 2-mm diameter scattering spot as seen from a distance of about 15 feet; (B) shows the same spot with the image strongly out of focus. The dark, center region is caused by the shadow of the small center mirror in the Cassegrainian telescope. Note that the total amount of granularity has changed very little, but the grains are larger and

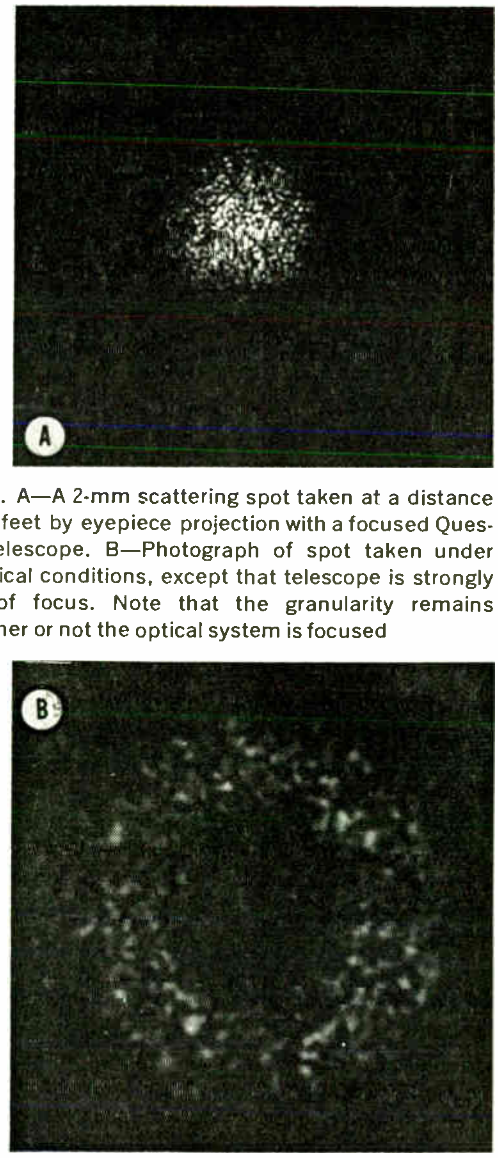


Fig. 6. A—A 2-mm scattering spot taken at a distance of 15 feet by eyepiece projection with a focused Questar telescope. B—Photograph of spot taken under identical conditions, except that telescope is strongly out of focus. Note that the granularity remains whether or not the optical system is focused

they are spread over a greater area, exactly as indicated in Fig. 1.

Scaling antennas with coherent light

Diffraction effects are not new to most engineers. The stubborn refusal of electromagnetic radiation to propagate in the nice straight lines of geometric optics is accepted as a "fact of life." While the antenna designer is concerned with directivity, main-lobe width, side-lobe amplitude (or null spacing) the lens designer must consider the effect of diffraction limits on the resolution of his optical system. And, where the antenna designer increases the diameter of his antenna to increase its directivity, the lens designer increases the diameter of his lens to improve its resolution. This parallel is more than coincidence; both are dealing with the same property of radiation, although in heretofore widely separated portions of the spectrum.

Recently, Skolnik[3] borrowed the "slits and pinholes" of the classic physics demonstrations to suggest a novel way of making scale models of antenna arrays. He proposed the substitution of a hole in a conducting plate for each driven element in the array. By illuminating the "holey plate" with radiation of the appropriately scaled microwave frequency, a pattern can be generated on the other side of the plate that is the same as if each hole represented an active radiating element. If the array is not too large with respect to wavelength, this technique has tremendous advantages over assembling the array with waveguide or coaxial feed lines connected to each element.

But, unfortunately, recent systems require very large arrays for space tracking and radio astronomy. The increase in size and number of driven elements has compounded the difficulty of calculating the pattern or space factor and has emphasized the need for testing with scale models.

The following technique extends Skolnik's method to permit scaling antennas that are hundreds or even thousands of wavelengths in diameter on a measurement range that is little larger than the average laboratory workbench.

The emergence of the helium-neon cw laser as a readily available laboratory tool makes possible a great extension of the holey-plate technique by taking the "slits and pinholes" back into the optical region of the spectrum. When operated in the visible region (6328 Å), the laser beam provides a stable source of plane waves with a very large diameter in wavelengths—about 1580/mm. These plane waves are used to illuminate an opaque screen that has holes corresponding to the elements of the array being scaled. The size and shape of the holes and their relative spacing are scaled down by the ratio of the light to the microwave wavelength.

For example, to scale an array to be operated at 3 Gc for evaluation with the 6328-Å helium-neon laser, the dimensions of the holey plate are related to the dimensions of the 3 Gc array by

$$\frac{\lambda_{\text{light}}}{\lambda_{\text{microwave}}} = \frac{6328 \times 10^{-10}}{10^{-1}} = 6.328 \times 10^{-6} \qquad (1)$$

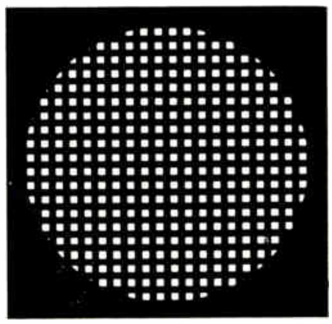
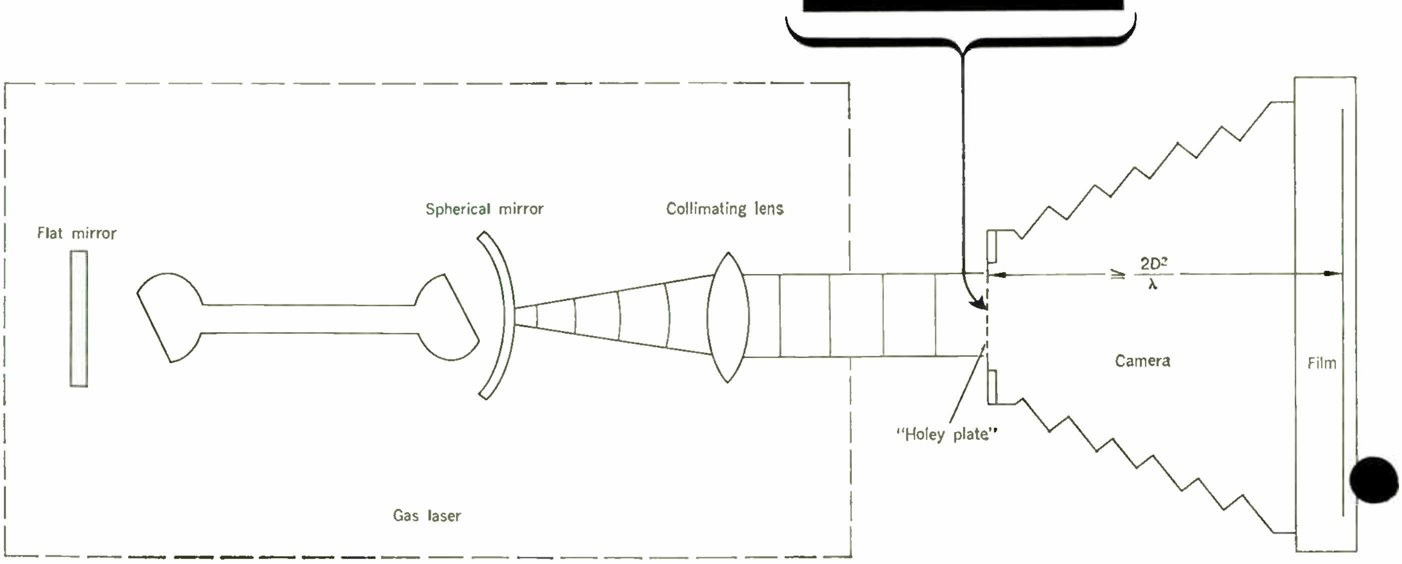


Fig. 7. Typical arrangement for simulating large antenna patterns with a laser. Photograph shows a test aperture, "holey plate," and its location in the apparatus diagram. The square mesh is electroformed nickel with center-to-center hole spacing of 0.001 inch (40λ). The overall array aperture is 0.020 inch (800λ)



It is apparent that such an extreme scaling factor will tend to restrict the technique described to antennas whose dimensions are all relatively large with respect to wavelength.

Several methods are available for controlling the characteristics of the illuminating source. But, for the purpose of this discussion, let us assume that we are dealing with a simple linear array of similar sources with equal spacing. The resultant far-field pattern can be described by simply multiplying the patterns of an individual source and an array of isotropic point sources as

$$E=f(\theta,\phi)F(\theta,\phi)\underline{\big/ f_p(\theta,\phi)+F_p(\theta,\phi)} \qquad (2)$$

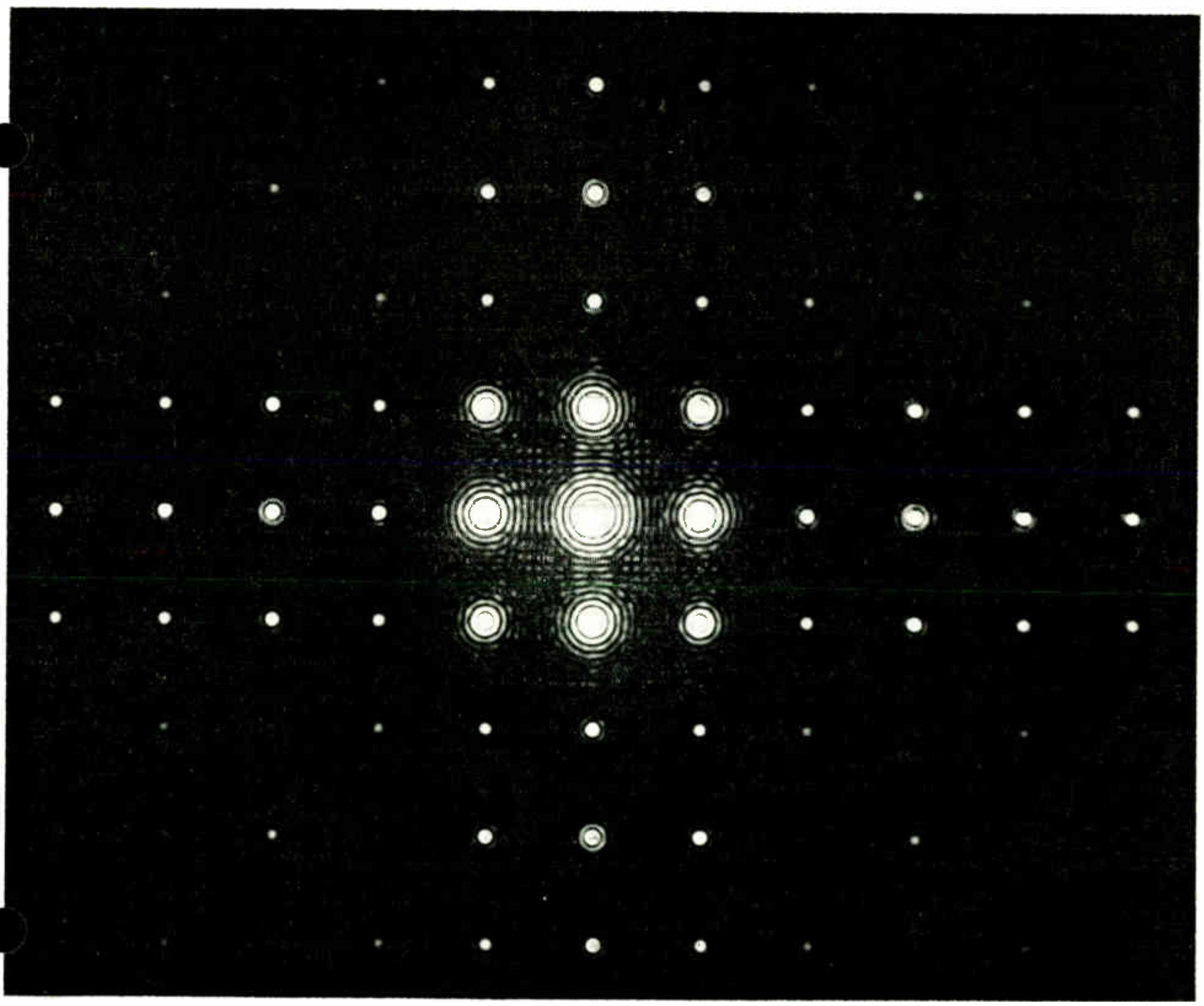
where the first two terms are the field patterns of an individual source and an array of isotropic sources, and the last two terms are their respective phase patterns.

There are several constraints on Skolnik's holey-plate technique and its described extension when an array is scaled that differs substantially from the uniformly illuminated normal or broadside array. The use of lenses to create spherical phase fronts in the illuminating source, or tilting the holey plate to obtain linear phase differences between individual sources also influences the phase pattern $f_p(\theta,\phi)$ of the individual source. Since large individual sources have already been specified, this effect must not be ignored in attempts to scale steerable arrays where the phasing is adjusted for E_{max} at angles other than 90 degrees to the linear array.

While phasing poses problems that have not been solved satisfactorily, polarization and amplitude distribution are more subject to control by the investigator. A "quarter-wave plate" gives circular polarization when the crystal axes are at 45 degrees to the polarization of the incident light, and other orientation angles provide all possible axial ratios of elliptical polarization.

It is often desirable to illuminate an array more strongly at the center and gradually taper the illumination to zero at the edges. The natural-mode patterns of the laser can be used quite effectively for approximating

Fig. 8. The resultant far-field pattern of the model array shown in Fig. 7. The two-dimensional surface of the picture represents the two spatial dimensions (E and H field) of the field pattern. This illustration does not show the last few nulls near the main lobes. These are clear in the negative



such tapered illumination. The TEM_{00q} modes, for instance, have a nearly Gaussian amplitude distribution, and it is necessary only to furnish the appropriate lenses to collimate the beam at the desired diameter ahead of the holey plate. Some of the same precautions mentioned in connection with phasing should be considered. However, smooth amplitude tapering should have small effect on the individual aperture field pattern $f(\theta,\phi)$, if this aperture is small with respect to the aperture of the array.

Operation in the visible portion of the spectrum has an advantage over microwave scaling. The pattern can be recorded directly on photographic film. It is easy to convert the film record to more conventional plots by merely scanning the negative with a densitometer and, if necessary, applying corrections for nonlinearities in the film response.

A typical equipment arrangement is shown in Fig. 7. A hemispherical mirror configuration in the laser is desirable, for it can be aligned readily for a simple, strong TEM_{00q} mode, and the spherical wavefront (from the curved-mirror end) can be allowed to expand to the desired diameter before being collimated to obtain the plane wavefront.

Punching, etching, and electroforming are all useful techniques for producing the relatively small holey plates.

An interesting property of this scaling technique is that the experimenter can see the actual pattern distribution. Calculation of the range required for far-field pattern measurement $2D^2/\lambda$, where D is antenna diameter and λ is wavelength, is noteworthy because of the magnitudes involved, but quite unnecessary in practice. Merely moving a piece of white paper away from the holey plate quickly shows the rather abrupt transition from Fresnel to Fraunhofer regions—and at surprisingly short distances for most apertures.

Figure 7 also shows a typical aperture which was produced by sandwiching an electroformed, square nickel mesh and a thin sheet of phosphor-bronze with a single, punched hole. The mask was coated with carbon black to prevent distortions caused by edge effects. Figure 8 shows the resultant pattern. The wide range of intensities in the figure is greater than the dynamic range of conventional printing processes. This illustration does not show the last few nulls near the main lobes, but they are quite clear in the original negative. Special films are now available with over 60-dB dynamic range of intensity, so this is not a serious problem.

In Fig. 8, the two-dimensional surface of the picture represents the two spatial dimensions (E and H field) of the field pattern. Simple geometry will quickly convert the linear dimensions to angular values.

The differential density of the film ($D_1 - D_2$) is directly related to the relative illuminating energy levels (E_2/E_1) by

$$D_2 - D_1 = \gamma \log \frac{E_2}{E_1} \tag{3}$$

where γ is the slope of the film's characteristic curve. The use of this expression—if the film γ is known—will permit conversion of film density to a quantitative plot of the far-field pattern. This represents a salient advantage over the simple qualitative evaluation of the pattern that may be obtained by merely viewing the distribution of Fig. 8.

This optical scaling technique could be readily extended to provide realistic, laboratory-sized models of mountain-ridge diffraction paths and other configurations of difficult analysis that are large with respect to wavelength. The cw laser should prove to be a powerful experimental tool for investigators in these areas.

Conclusions

Two principal conclusions have been reached on the basis of all the diffraction experiments described.

The new relationship between the typical size of target-surface irregularities and wavelength will probably cause severe amplitude fluctuations at the detector in optical radars.

The same phenomenon gives high promise of providing rapid tracking capability by direct measurement of tangential target velocity.

It is evident from the previously described experiments that the spatial and even temporal coherence of the gaseous laser beam can produce most interesting scattering effects. These experiments also provide sufficient information to engage in some speculation about future optical electronic systems.

It is quite probable that the high directivity possible in this region of the spectrum will permit practical illumination of relatively small target areas at great range. If so, the detector used in such a system will have to operate in the sort of field pattern shown in Fig. 2. If the detector aperture is small and at great distance from the target, any tangential motion of the target with respect to the illuminating source can be expected to produce large fluctuations or scintillations in the detector output. Some initial investigation of metallic surfaces has shown the same random intensity patterns as the test paper, though polarization is not at random, as it from the paper.

If an array of detectors (with proper correlative interconnection) or an imaging system is used to examine the target returns, a potentially annoying effect could be turned into a unique advantage. The sweeping motion of the random-field pattern is a direct function of the tangential-velocity vector of the target in the beam. Therefore, it should be possible to obtain angular tracking information on a nearly instantaneous basis. It is also possible to modulate the beam to obtain range and radial-velocity data. The additional information on relative tangential velocity is all that should be required to maintain continuous track on a target in three dimensions.

Proposed optical electronic systems will encounter monumental problems in acquisition—but the ability to establish rapid tracking of an acquired target could improve some proposed systems significantly.

REFERENCES

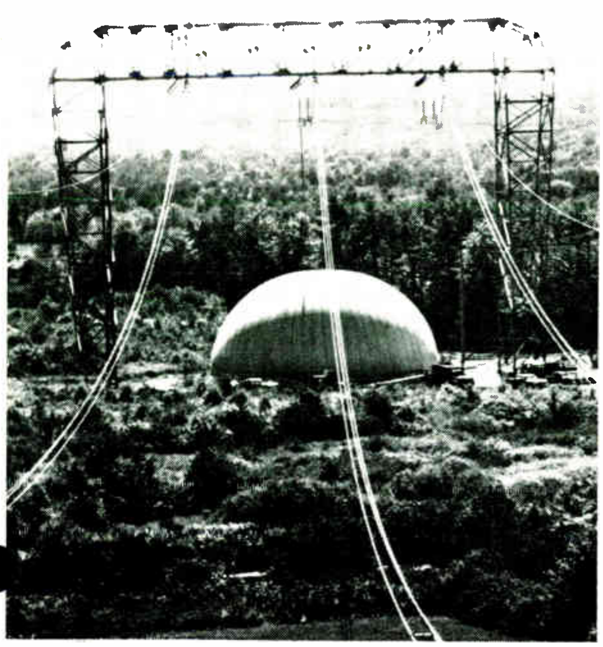
1. Oliver, B. M. "Sparkling Spots and Random Diffraction," *Proc. IEEE (Correspondence)*, vol. 51, Jan. 1963, pp. 220–221.
2. Langmuir, R. V. "Scattering of Laser Light," *Appl. Phys. Letters*, vol. 2, Jan. 15, 1963, pp. 29–30.
3. Skolnik, M. J. "A Method of Modeling Array Antennas," *IEEE Trans. on Antennas and Propagation*, vol. AP-11, Jan. 1963, pp. 97–98.

This article is based on a paper presented by the author at the 1963 Western Electronic Show and Convention at San Francisco, August 20–23.

EHV ac and dc transmission

EHV is used to move large blocks of power when distances between power source and load are great. On existing transmission structures, one 500-kV line could replace six 230-kV lines, as far as loading capability is concerned

J. J. W. Brown, E. M. Hunter *General Electric Company*



As the electric utility industry enters the year 1964, the list of utilities in the United States with 500-kV projects under way and expected to be in service by the mid-1960s is most imposing: Virginia Electric Power Company; Pacific Gas and Electric Company; Southern California Edison Company; Pacific Power and Light Company; Bonneville Power Administration; South Central Electric Companies: Tennessee Valley Authority; Pennsylvania–New Jersey–Maryland (P-J-M) Utility Group; and Allegheny Power System, Inc. In addition, a large number of new 345-kV projects have been started. The July 8, 1963, issue of *Electrical World* estimates a total of 5450 circuit miles of EHV interconnections planned between 1964 and 1970. Of these, 2210 miles will be at 345 kV and 3230 miles at 500 kV and higher. Similar growth is also to be found in Canada and overseas and is, in fact, world-wide.

Extra-high-transmission voltages (EHVs) are defined at voltage levels above 230 kV. To put this expansion of system voltages in its proper perspective, let us briefly trace its growth. In the United States, 230 kV was first com-

GE surge generator site for full-scale EHV tower testing missioned in 1923, 287 kV in 1936, and 345 kV in 1953. Today, 345 kV is the highest commercial voltage in the United States. Overseas, Sweden energized 400 kV in 1952; this voltage in the ensuing years has been adopted by Finland, West Germany, Austria, France, Italy, Great Britain, Spain, and Switzerland. In Africa, South America, and Australia 345 kV is being used but on a limited scale. At present, the line mileage outside the U.S.S.R. is estimated to be 4000 at 345 kV and 5600 at 400 kV.

The U.S.S.R. installed its first 400 kV line in 1954. East Germany, Czechoslovakia, Hungary, and Romania followed suit shortly thereafter. Then, in 1961, the U.S.S.R. found it expedient to raise the EHV level to 500 kV.

With regard to the future, there appears to be no contemplated 500-kV transmission expansion for western Europe. In Canada, however, as well as the United States, line construction is now under way and terminal equipment is on order for 500-kV projects that should be commissioned by the mid-1960s. Canada will also have a 700-kV project in partial service by 1965 and fully commissioned by 1967 or 1968. This is the first 700-kV project to be undertaken by any nation. (The U.S.S.R. reports studying 700 kV and plans for a network by 1969.)

The achievement of a heretofore unattained EHV level has moved from country to country. Some critics of the industry have used this as a criterion of progress. Far more significant criteria, however, are the proper voltage level and development and application of the new higher voltage in time to meet the needs of industry expansion.

I. Electric utility peak loads

Companies	Winter Peak MW	Rank
Tennessee Valley Authority (TVA)	12 124	1
American Electric Power	5 638	2
Pacific Gas & Electric	5 500	3
Commonwealth Edison	4 996	4
Consolidated Edison	4 373	5
Southern California Edison	4 157	6
Niagara Mohawk	3 201	7
Duke Power	3 192	8
The Detroit Edison	3 119	9
Public Service Electric & Gas	2 921	10
Georgia Power	2 766	11
Philadelphia Electric	2 711	12
General Public Utilities	2 303	13
Florida Power & Light	2 130	14
Virginia Electric Power	2 076	15
Consumers Power	2 066	16
Alabama Power	2 007	17
Allegheny Power	1 953	18
Ohio Edison	1 894	19
City of Los Angeles	1 840	20
Pacific Power & Light	1 794	21
Union Electric	1 670	22
New England Electric System	1 643	23
Northern States Power	1 638	24
Pennsylvania Power & Light	1 556	25
Houston Light & Power	1 540	26
Carolina Power & Light	1 516	27
Duquesne Light & Power	1 254	28
Public Service of Indiana	1 221	29
Long Island Lighting	1 206	30

Alternating voltage selection

In 1947 the International Electrotechnical Commission (IEC) selected 400 kV as an international standard. It was an increase of 173 per cent above 230 kV, the highest voltage then in use in Europe.

At about that time, 345 kV was selected in the United States as the overlay voltage for an existing 138-kV system. The 2.5 factor between the old and the new voltage was economically sound.

It is generally conceded that neither 345 nor 400 kV is a suitable voltage to superimpose on a 230-kV system, as neither is high enough.

An acceptable criterion in selecting a new voltage is to have a ratio of 2.0 to 2.5 between the superimposed and existing voltage. The IEC at its 1963 meeting in Venice, Italy, approved the addition of 500/525 kV and 700–750/-765 kV to its list of standard voltages.

ASA Sectional Committee C92 on Insulation Coordination and EHV's is contemplating changes to its Standard ASA C92.2 "EHVs" by changing 500/525 kV to 500/550 and 700/735 kV to 700/765. The change to 550-kV maximum voltage will support the practice on United States 500-kV systems and the 765-kV maximum is in accord with the IEC Standards.

These days, new voltage levels come to fruition much sooner than expected. However, in the United States, the prevailing opinion is that a 700-kV network will not be needed before the mid-1970s. However, while 700 kV could be accepted as a suitable overlay for 345 kV, it is not economically sound for 500 kV. Should there not be in the Standards a superposition voltage for 500 kV? It is suggested that 1000/1100 kV be considered for future studies and investigations. Before the end of the century, it might be needed.

Why EHV?

Power losses in a transmission line are a function of the impedance and the square of the current; thus, raising the voltage lowers the current proportionately, which helps compensate for the increase in impedance with distance. Extra-high voltages, therefore, are economically applied when the distances are great between the power source and the load. Sweden, for example, is a country without known deposits of fossil fuels but with a substantial supply, in the northern part of the country, of potential hydro power. However, the load for the output of these plants is in the southern part of the country. The first 400-kV line in Sweden ran about 600 miles between the hydro site in the north to the load center (Stockholm) in the south. A similar load-generation distance situation exists in the U.S.S.R.

In Great Britain, on the other hand, these great distances are not encountered. However, with the high density of population and with the pressures to preserve the appearance of the countryside, transmission rights of way are very difficult to obtain and those at hand must be utilized to their full capability. The higher voltages in Great Britain are needed to load the rights of way.

In the United States, EHV transmission is used to move large blocks of power. While there is an extensive land mass in continental United States, about 10 per cent of it is underlain by coal deposits. These have wide geographic distribution. While there are a few remote coal fields and hydro sites yet to be developed, transmission lines longer than 150 to 200 miles are relatively rare because of the relative proximity of fuel sources to load centers. However, new rights of way to some of our metropolitan centers of population are most difficult to come by; public opposition to overhead construction is growing, and use of public lands for this purpose is being hedged with restrictions, making it more and more necessary to utilize fully whatever is in place. The full significance of this statement is better appreciated when it is considered that one 500-kV line could replace six 230-kV lines as far as loading capability is concerned. (See the Appendix.)

Incentives for EHV transmission growth

The rate of growth of electric utilities is such that they must plan and construct a facility equal in size to the one in place on the average of every ten years. In 1962, the investor-owned electric utilities announced that they would spend $8 billion in the next eight years to expand their transmission networks. This amount, together with government expenditures (approximately 25 per cent of the total) is a sizable investment.

Furthermore, of the total investment in an electric utility system—generation, transmission, and distribution—expenditures for low-voltage transmission are approximately 20 per cent. EHV transmission expenditures, however, are closer to 25 per cent; thus, these latter expenditures play an important role in system financing.

Any one of several factors may be the deciding incentive for installing a new EHV line. The new line may be used for an overlay of existing transmission facilities to provide the backbone of the system of the future. However, EHV transmission can be used only by the larger systems because the economic loading capabilities are so great they cannot be fully utilized on smaller systems. *Electrical World* for March 18, 1963, alphabetically listed utility companies and their December 1962 peak loads. These data, listed in descending order of peak loads, are shown in Table I. One may readily observe that (1) only 17 companies have a peak load in excess of 2000 MW, which is about the surge impedance loading of a 700-kV line; (2) it would not be sound engineering to transport the total load of any company over one line; and (3) existing and planned EHVs through 500 kV are sufficient for overlay purposes at present.

On the other hand, EHV transmission may be used to provide the grid to interconnect neighboring utilities whereby the individual companies can share economically the installation of relatively large generating plants and give and receive mutual support in times of emergencies. The pooling of resources through interties can support higher transmission voltages than could be justified by the individual member companies comprising the pool.

Last but not least, EHV transmission may be the prime factor in allowing a wider choice of sites for new generation facilities. Remote low-cost fuel plants at mine mouths where essential cooling water is available, or remote hydro sites that could be exploited, increase in economic attraction with increases in the higher voltage levels and the bulk power to be transmitted.

It should be noted that some or all of the above factors were compelling incentives for the 500-kV EHV projects enumerated at the beginning of this article.

A first attempt at appraisal of the economics of various means to move large blocks of power long distances is given in Fig. 1. It shows present-day energy transportation costs in mills per kWh as a function of distance, and compares EHV transmission costs with the cost of moving coal by rail. It should be recognized that the results presented must of necessity be average figures and specific studies might produce different break-even points.

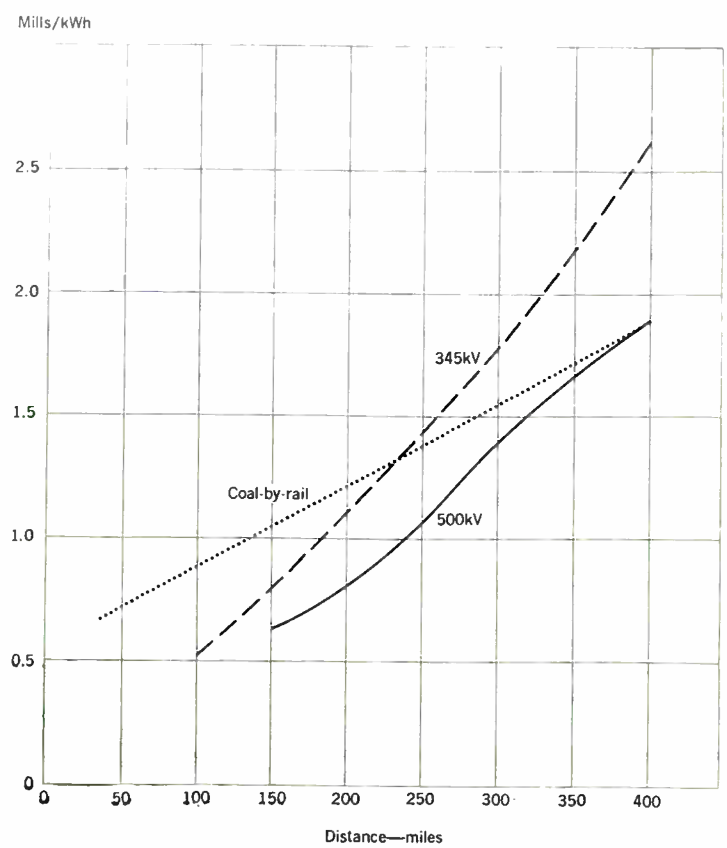
EHV transmission techniques

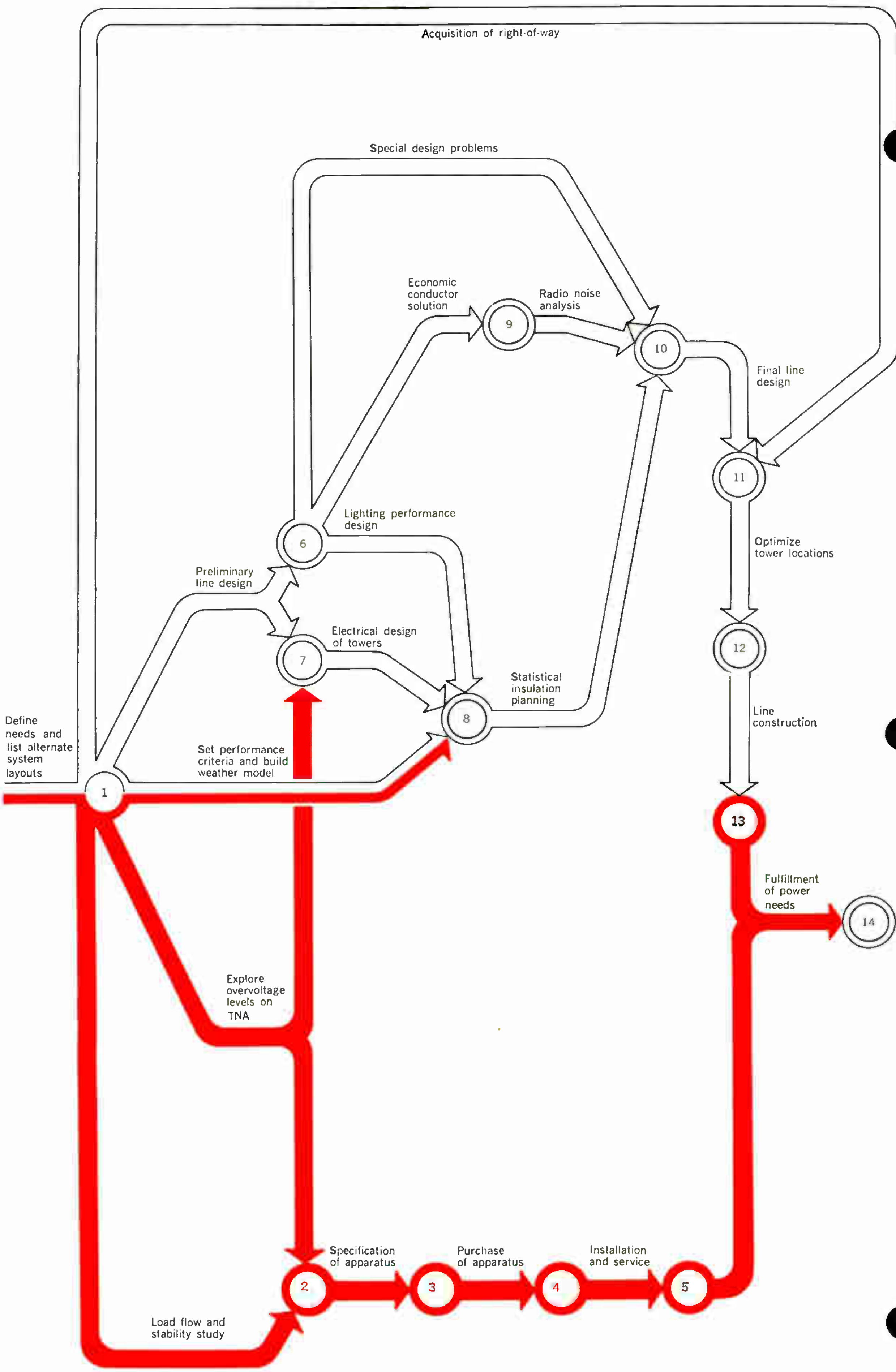
Certain techniques, somewhat peculiar to EHV transmission, have been developed to reduce to acceptable standards some of the problems encountered to make the systems serviceable and economical.

EHV transmission systems may be subjected to dynamic overvoltages owing to the large charging kVA requirements. It is well known that the flow of reactive charging current through a reactance, such as is found in a power transformer, produces a rise in voltage. If, however, the line reactive current is compensated by shunt reactive current, the dynamic overvoltages can be controlled. Shunt reactors are available for this purpose. The application technology must be able to resolve whether the shunt reactors should be located on the high- or low-voltage systems, and when they should be switched in and out of the system.

Transient overvoltages from internal origin can increase system insulation requirements; hence there is considerable economic incentive to keep them to minimum levels. Fortunately, they are for the most part internally generated and therefore predictable and controllable. Most of these overvoltages result from switching operations. EHV circuit breakers have series resistors that can

Fig. 1. Transmission costs based on optimum loading of two-circuit transmission from base-loaded station (90 per cent transmission load factor). Receiving system, 138 kV; 15 per cent annual carrying charge; average coal-by-rail costs based on 9000 Btu/kWh plant heat rate





Acquisition of right-of-way
Special design problems
Economic conductor solution
9
Radio noise analysis
10
Final line design
11
Optimize tower locations
12
Line construction
13
Fulfillment of power needs
14
Lighting performance design
6
Preliminary line design
7
Electrical design of towers
8
Statistical insulation planning
Define needs and list alternate system layouts
1
Set performance criteria and build weather model
Explore overvoltage levels on TNA
Specification of apparatus
Purchase of apparatus
Installation and service
2
3
4
5
Load flow and stability study

Fig. 2. A critical path diagram for EHV transmission design

be preinserted on closing operations, and are designed to prevent restriking on opening operations. With these measures, the switching overvoltages of 3.0 or higher formerly encountered may now be limited to the order of 2.0 times normal.

EHV transmission circuits may also require series compensation for the line's inductive reactance to improve either stability or load flow. The series capacitor with its protective gap is available as an aid in the moving of bulk power over great distances.

To improve stability for remote generating plants, dynamic braking resistors need to be considered. The resistors (electric brakes) are switched onto the system as overspeeding occurs to act as the load absorbing the input to the prime movers until adjustments can be made. The basic principles of application of series compensation and dynamic braking to achieve system stability are understood. In fact, they have been thoroughly studied by system planners for at least 30 years but only with EHV transmission have they received new impetus.

EHV designs by the critical path method

There are many technical decisions to be made during the design stages of an EHV project. They must come at the proper time and in orderly sequence because decisions in one area often hinge on conclusions in several others.

As an aid in thinking through one of these undertakings, a critical path diagram can be prepared similar to that shown in Fig. 2. Each numbered circle represents a decision point which may be either provisional, intermediate, or final. Each arrow connecting the circled decision points represents an activity.

The lower portion of the diagram embracing decision points 1 through 5 covers system performance and the specifications for the purchase and installation of substation terminal equipment. The upper portion involving decision points 6 through 13 involves the electrical and mechanical design of the transmission line and towers. Thus, this critical path diagram gives a bird's-eye view of what must be accomplished from the time the decision has been made to go ahead with the project to the fulfillment of the undertaking.

Many engineering tools are available that may be used in getting facts for decision making. Load flows and stability problems are studied by the well-known analog and digital computers. System overvoltage magnitude, if from internal origin, can be established on the Transient Network Analyzer (TNA) when the system is set up in equivalent miniature and tested. Lightning performance can also be predicted by geometric scale models. Full-scale tower tests using an impulse generator at the General Electric Company's Project EHV will give full assurance that the insulation used will develop the strength needed in service. Project EHV has also added much in the way of basic data and understanding in the areas of corona and RIV (radio noise influence voltage) which aids in the selection of the economic conductor size.

Meteorological integrated forecasting

Troubles on transmission lines and the attendant interruptions of service are, for the most part, oriented with adverse weather conditions. Hourly records of weather for periods up to 15 to 20 years are available from the United States Weather Bureau. Statistical models constructed from these data integrated into a computer program can be used to assess the lifetime performance of any particular line design. For example, the program can judge the possibility of the occurrence of maximum switching surges or maximum lightning voltages at a time when factors such as air density, humidity, precipitation (rain, snow, sleet), and wind (proximity of conductor to tower leg) are least favorable to the maintenance of insulation strength.

Two types of management decision questions that can be answered by the meteorological integrated forecasting (METIFOR) approach are:

1. Given a fixed line investment, what is the optimum allocation of expenditures to produce the maximum in service continuity?

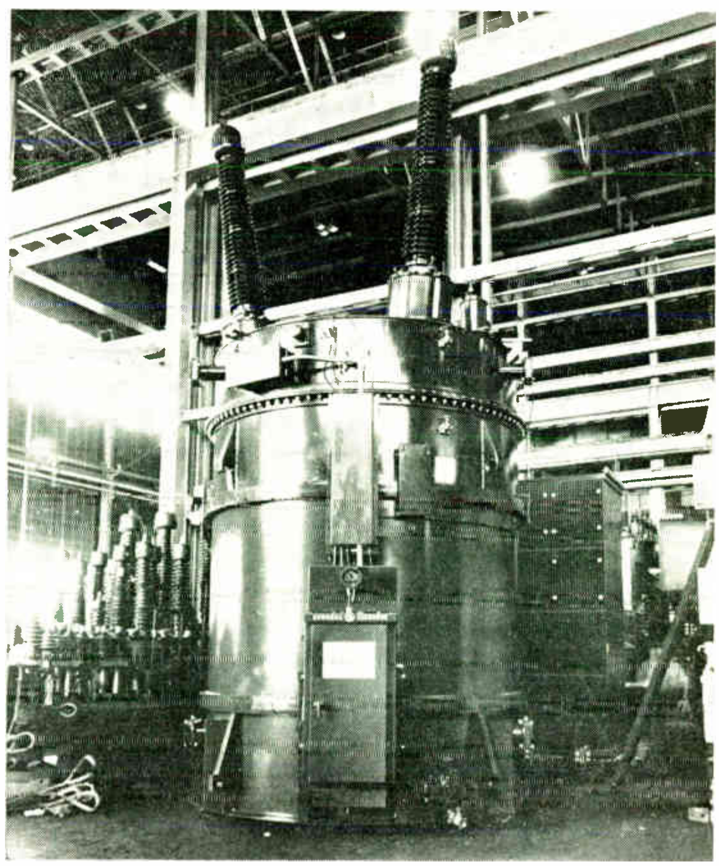
2. Will increasing line investment produce a justifiable increase in performance or not?

Power transmission with HVDC

HVDC (high-voltage direct current) transmission is a scheme by which power can be rectified from 60-c/s current to direct current and transported to the load center where it is inverted from direct current to 60-c/s current for distribution and utilization by the ultimate consumer. It is a relatively new tool in power transmission.

The first commercial application in the world was placed in service in 1954 between the Swedish mainland and the island of Gotland. Twenty MW is delivered over

View of GE three-phase 230-kV 65 000-kVA shunt reactor



a 60-mile single-conductor cable at 100 kV. This application which was made by Allmanna Svenska Elektriska Aktiebolaget (ASEA) has provided experience and encouragement for additional undertakings.

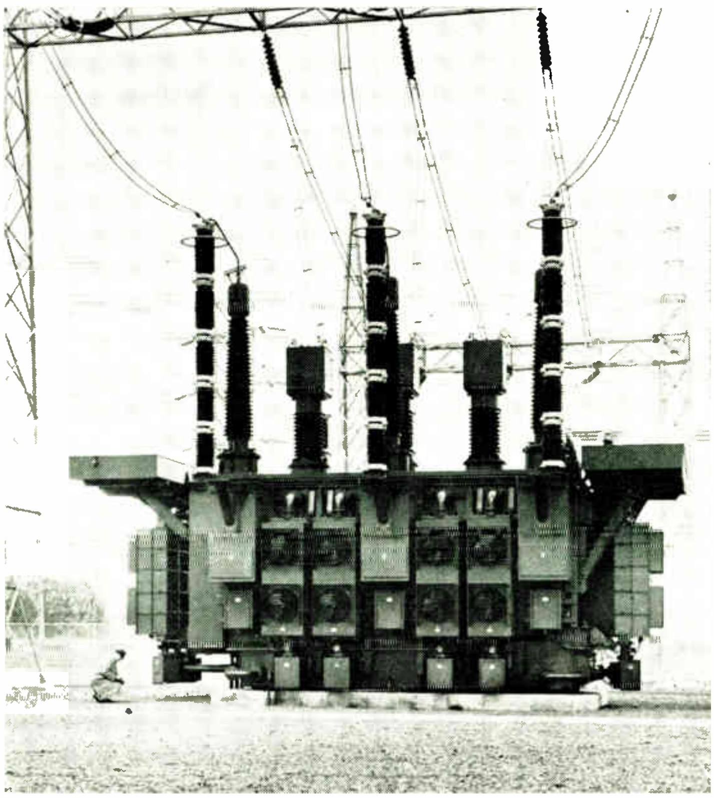
The second application was the tie between France and England. This link through 40 miles of cable across the English Channel is suitable for transporting 160 MW at ±100 kV in either direction.

To date, outside of the U.S.S.R. contracts have been let for four other projects as listed in Table II. ASEA mercury-arc valves will be supplied in all of the new applications although the English Electric Company is supplying the other equipment on the Italy–Sardinia undertaking.

II. Summary of HVDC transmission systems

Location	Installation Date	Rating kV	Rating MW	Type of Transmission
Island of Gotland	1954	100	20	60-mile cable
English Channel	1961	±100	160	40-mile cable
Donbass–Volgograd (U.S.S.R.)	1964	±400	750	300-mile overhead
New Zealand	1965	±250	600	25-mile cable 360-mile overhead
Italy–Sardinia	1965	200	200	61-mile cable 217-mile overhead
Japan (50-60 c/s)	1965	±215	300	
Konti-Skan (Denmark–Sweden)	1965	250	250	53-mile cable 59-mile overhead

View of GE 345-kV transformer rated FOA-T 200 MVA, showing three bushing-mounted load-tap changers on top and two Atmoseal oil expansion tanks on either side



The U.S.S.R. scheme employs two valves in series for a 100-kV bridge and a basically different valve design. At the time of this writing, this project is reported to be operating at ±100 kV with the expectation that it will be at full voltage of ±400 kV in 1964.

Technical feasibility of HVDC transmission has been proved in the applications made to date. Economic feasibility needs to be studied on each application considered.

HVDC transmission has economic potential in bulk power transmission in four categories: (1) overhead remote source-to-load transmission; (2) underwater cable transmission; (3) underground cable to distribution networks in large cities; and (4) conversion tie between large networks of different frequencies.

These are all point-to-point applications. The future possible use of HVDC transmission in integrated networks will require a great deal of study, taking into consideration the high cost of terminal equipment and that the controls for multitapped lines will require attention.

As already mentioned, in this country power sources and load centers for the most part are geographically so situated that there has been little need for transmission lines over 150 to 200 miles in length. However, there are some remote coal fields in the western part of the United States and underdeveloped hydroelectric sites in Canada where the distances become much greater. Some of these remote power sites are being studied and comparisons of series and shunt-compensated ac lines have been made with HVDC. If the transmission route includes a section requiring cable, economics favor HVDC because of the higher permissible dc loadings of cable.

HVDC terminal equipment is more expensive than that required for ac transmission. On the other hand, HVDC transmission lines cost approximately 70 per cent of an equivalent ac line. On the French–English cross-channel application, roughly two thirds of the investment covers terminal equipment and the other one third goes for cable. If the application had been ac, these percentages would have been reversed; i.e., one third for terminal equipment and two thirds for cable. The economics of the application was such that the application was at the break-even point between ac and dc. The nonsynchronous features of the dc tie was one of the deciding factors in favor of HVDC.

With regard to the immediate future, the high cost of HVDC terminal equipment limits HVDC transmission to applications where large blocks of bulk power are to be transported on a point-to-point basis over great overhead or cable distances. There probably will be only a limited number of these applications in the next decade or so but each could be a massive undertaking.

APPENDIX

The surge impedance of a line may be expressed approximately as $C \times (\mathrm{kV})^2$, where C equals 2.5 for single conductors and from 3.0 to 3.5 or greater for bundled conductors, depending on whether two or more conductors are in the bundle. The surge impedance loading (SIL) of 345 kV is on the order of 300 MW, 500 kV is 800 MW, and 700 kV is 1800 MW. The economic loading is often expressed in multiples of surge impedance loading and may vary from 1.0 SIL to 3.0 SIL, depending upon the transmission distance, series compensation used, number of circuits with intermediate switching stations, and stability of the system.

The surge impedance loading of a 230-kV line is equal to $2.5 \times 230^2 = 133$ MW. Similarly, for a 500-kV line, it is between $3.0 \times 500^2 = 750$ MW, and $3.5 \times 500^2 = 876$ MW. Thus, 750 divided by 133 is 5.62 and 876 by 133 is 6.57. Six lines is, therefore, a good approximation.

The U.S. basis of electromagnetic measurements

Whenever technology outstrips our ability to measure, the result is poor reliability, overdesign, and delays. Here is how a radio standard evolves, and how NBS is striving to shorten the standards time lag

John M. Richardson, James F. Brockman *National Bureau of Standards*

The undersigned believe that the following material, describing the national basis of electromagnetic measurements, deserves the thoughtful consideration of all members of the IEEE, and we have recommended that it be brought to their attention through this publication.

The size and importance of the electrical and electronics industry is clear to all members of the IEEE without the need of statistics. What may not be so clear is that this whole industry must rest on a uniform base of accurate and precise measurement if it is to achieve in practice the results which physicists and engineers find possible in principle. That base can only be provided by the National Bureau of Standards. However, the provision of a uniform base of measurement is costly in manpower, laboratory space, equipment, and time because of the great scope of electromagnetic quantities in kind, frequency, magnitude, and accuracy.

There is a strong indication, from some of the material presented, that the provision of that base has not kept pace with the growth of the industry. We believe that the National Bureau of Standards is making strong efforts to discharge the task assigned to it by Congress, but we also believe that the importance and magnitude of the problem call for understanding and support from outside NBS. It is from this standpoint that we recommend to members of the profession the reading of this article.

A. A. Oliner, Chairman — *E. C. Jordan*
S. A. Bowhill — *R. Kompfner*
W. Gordy — *W. A. Lewis*
E. L. Hahn — *N. F. Ramsey*
E. W. Houghton — *J. C. Simons, Jr.*

Members, National Academy of Sciences–National Research Council Advisory Panel to the Radio Standards Laboratory of the National Bureau of Standards.

In 1911, J. V. L. Hogan, one of the founders of the IRE, asked the National Bureau of Standards to calibrate a wavemeter. The job was given to a young employee, J. Howard Dellinger, who, 50 years later, described the event as follows:

"I was working in the Inductance and Capacity Section, in part of a room in the South Building. I was taking a course in Maxwell and had been intensively studying high-frequency phenomena. So this job was handed to me. It had to be in the Inductance and Capacity Section, for how else could you make a frequency standard at radio frequencies than by setting up a resonating *LC* circuit? I had to improvise such a circuit which generated the current, and the crystal rectifier to detect resonance, all without vitiating the value of frequency calculated from the *L* and the *C*."

Thus was the first radio calibration made by the National Bureau of Standards. Apparently the work was satisfactory since Dellinger later became chief of the NBS Central Radio Propagation Laboratory and was elected president of IRE.

From one man, the Bureau's effort in radio standards has grown to a staff of 300 people, who form the Radio Standards Laboratory. The Laboratory's purpose is to provide the central basis for electromagnetic measurements in the United States and to assure their international coordination. Thus it provides the measurement foundation for the electronics industry—an industry that has multiplied about 35 times during the past 25 years while the gross national product has increased only by a factor of six.

Pressure from the research frontiers

Electronics' first big leap forward came with the widespread use of radar during World War II. NBS felt the impact through a request from the Joint Chiefs of Staff dated April 26, 1944:

"The Joint Communications Board has decided that there is a need by our Armed Forces for primary radio frequency standards for frequencies between 1,550 and 11,000 megacycles per second. These standards are necessary for the proper calibration of secondary standards by which the radio equipment of our Armed Forces can be calibrated in the field. No primary standards of frequency determination for use in the radio spectrum between 1,550 and 11,000 megacycles per second are now known to be available. . . ."

The need was clear-cut, the reasons behind it were well defined, and the need could be considered with little concern for large simultaneous improvements in other quantities. This was probably the last time that major measurement needs in the field could be so clearly and succinctly summarized.

Since 1944, electronics has enjoyed spectacular growth in both size and scope. Its importance in new, extreme, and complex environments means continual pressure for extending the useful range of electromagnetic energy. This in turn means continual and substantial pressure for improving the art of radio measurement—to higher frequencies, to different magnitudes (both high and low), and always with greater accuracies.

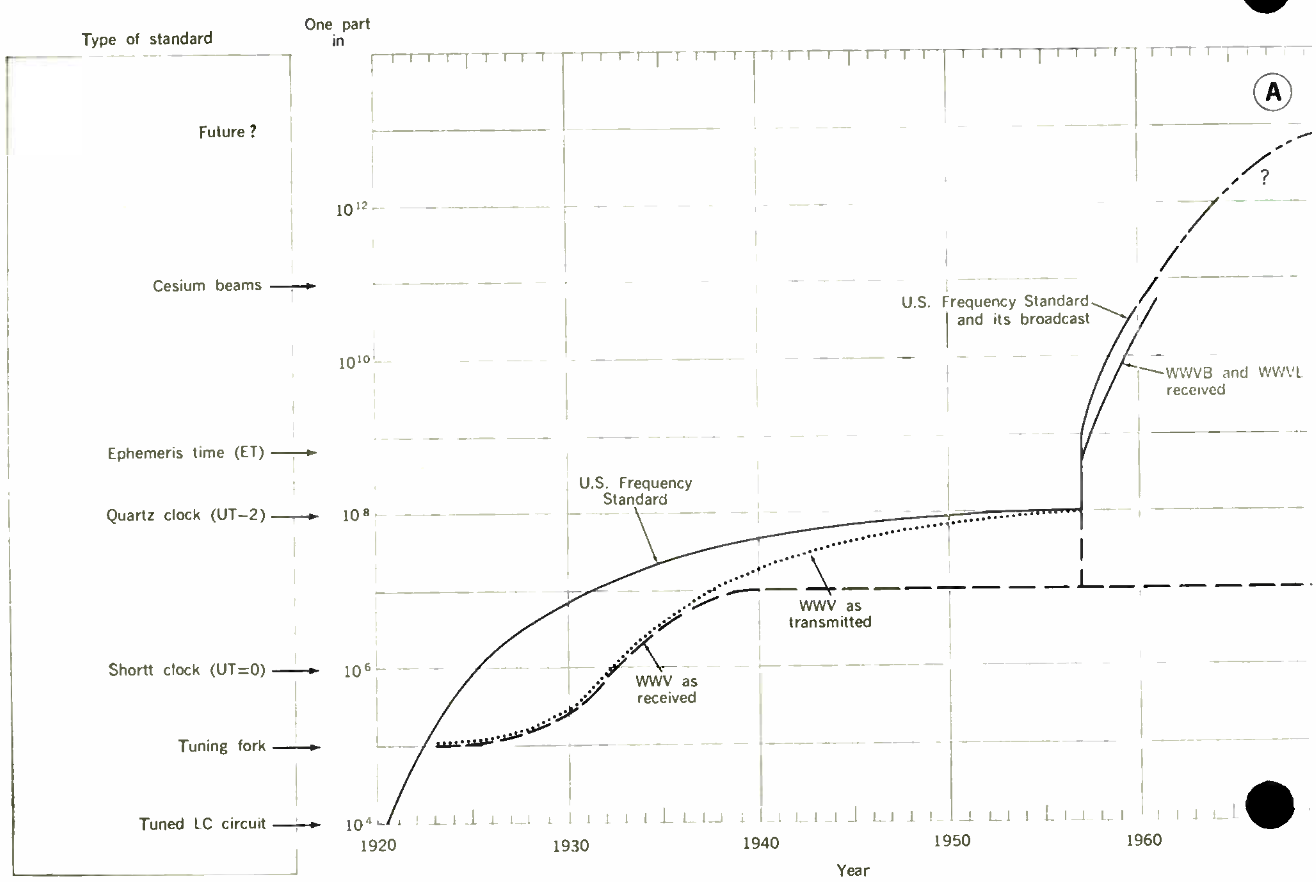
This pressure for the extension of radio measurements is augmented by the swift application of new discoveries. It is well known that the lag time between the discovery and application of major developments is swiftly decreasing; over 50 years for electric power generation, about 4 years for the transistor, about 19 months for the laser. A consequence of this acceleration is that new standards are desired barely moments after discovery.

Effects of a measurement gap

With the need for better standards, more standards, and the rapid development of standards, it is not surprising that technology sometimes outstrips the science of radio measurement. It should also come as no surprise that this lack of measurement creates spectacular problems. Usually, however, these problems are not recognized as being the result of inadequate measurement, for standards of measurement tend to remain hidden in the background.

Since 1960, NBS has been meeting with members of the Aerospace Industries Association to compare industry's measurement needs with the services offered by NBS. This has helped define the needs more precisely and has provided some measure of their relative urgency. The meetings have also uncovered many specific illustrations of how industry is affected when a standard of measurement does not exist—when there is a measurement gap. Some of the effects are:

- Disagreement between contractor and subcontractor as to whether a product meets specifications.
- Poor reliability.
- Excessive time required to produce equipment by trial and error since, if the component characteristics are unknown, it is impossible to predict performance accurately.
- Need to overdesign to be sure the product will do the job.
- Schedule delays caused by inacceptable components and systems.
- Duplication of effort.



The dramatic quality of our national defense and space programs, and the fact that most unsatisfied customers of the Radio Standards Laboratory are tied to these programs, may create the feeling that improved electromagnetic standards need only concern those whose work is related to the defense and space efforts. It should be apparent, however, that better measurement in these areas affects the entire national economy.

The National Aeronautics and Space Administration has estimated that about 90 per cent of space systems failures are electronic; it seems reasonable to assume that a portion of these are due to inadequate measurement.

While visiting our laboratory last year, H. L. Balderston of the Boeing Aircraft Corp. referred to the early (1952–1954) flights of the Bomarc missile which occurred before the Department of Defense was insisting that weapons systems be tested by instruments whose calibration was directly traceable to the U.S. standards at NBS. None of the first six test flights was completely successful. The next missile, thoroughly tested with measurement traceability, was the first Bomarc that accomplished all flight test objectives and marked the turning point in a successful flight test program.

Obviously it is important to both industry and the taxpayers that the expense of these programs be kept at a minimum by the very best measurements we are able to provide. And experience shows that meeting the extreme demands of advanced technologies often provides the ability to meet similar needs as they develop in such fields as telephone, radio, television, electric power, and industrial process control.

Fig. 1. Evolution of a national standard. Improvements in the accuracy of the U.S. national frequency standard (A). New cesium beam standard (also usable with thallium) was built and is now being evaluated by the NBS Radio Standards Laboratory (B). Its 18-foot length should reduce spectral line width to about 45 cycles as compared with 110 cycles in the previous 10-foot model, and should increase precision significantly. Improved frequency stability of WWV due to control by low-frequency broadcasts from WWVB and WWVL (C)

Major users

Verification of cosmological theories
Fundamental relativistic experiments
Deep space research and development
National and international frequency standards

National coordination of standards laboratories
Aerospace research and development laboratories

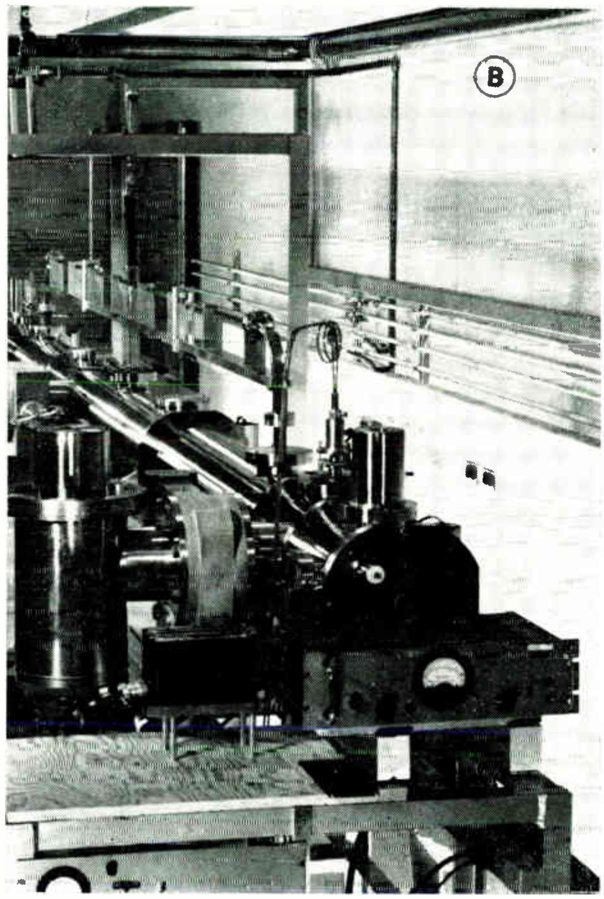
Aerospace operations (doppler tracking)
Research laboratories
Instrument manufacturers
Space navigation, velocity of light experiments

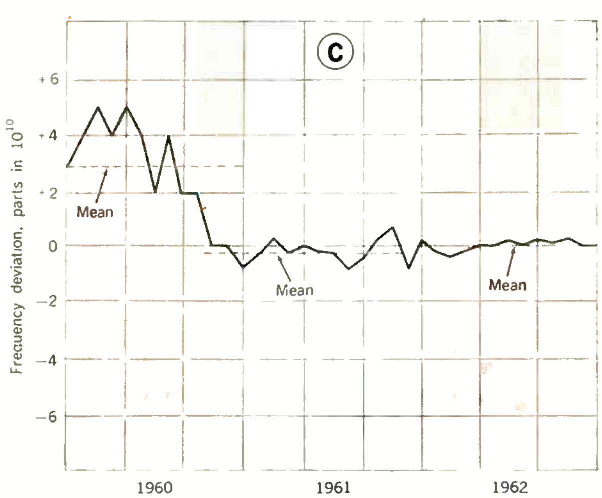
Optical satellite tracking
Air navigation, astronomy

Radio and TV servicing
Automatically controlled clocks

Radio and TV broadcasting, radio communications
Radio amateurs, telephoto, facsimile

Surface transportation
Power companies, telephone companies





How a national standard is developed

The pressure for new and more accurate standards of electromagnetic measurement means that the Radio Standards Laboratory is continually faced with requests for crash development. This pressure provides an exciting stimulus, but it has forced the staff to concentrate on developing calibration services at the expense of national standards of measurement.

A standard of measurement grows from fundamental research. It evolves through theoretical work that applies the fundamental principle to a particular measurement problem. It matures as the instrumentation and procedures that provide a standard, and finally a calibration service, are developed and evaluated.

Development of a national standard is illustrated by the evolution of the United States Frequency Standard, presently obtained from cesium atomic beams. The fundamental research on which these machines are founded was done by Rabi and his associates about 1940. NBS published early research results of the development of an atomic frequency standard in 1949, and the first machine began reliable operation in 1957. But this machine was not accepted as a standard until a second one was completed and independently evaluated.

The independent testing of each machine, together with a comparison of their frequencies over a period of three years, establishes our confidence in the quoted accuracy with respect to the idealized atomic transition frequency (about 1 part in 10^{11}) and precision (about 2 parts in 10^{13} for a 12-hour averaging time). What these machines mean in the evolution of the U.S. Frequency Standards is shown in Fig. 1(A).

Now the staff is evaluating a new cesium beam, Fig. 1(B), which is longer and therefore should be more precise. They have also developed thallium beams to evaluate their potential as frequency standards, and are exploring the possibility of using lasers.

During development of the cesium beams, the staff was also concerned with making the frequency standard available to others. The instabilities of high-frequency propagation require averaging the signals from station WWV for a period of up to 30 days to achieve a precision of 1 part in 10^{10} (the usual, quickly attainable precision is only about 1 part in 10^{7}), and reliable reception is limited to a few thousand miles. In 1959, several major organizations, including NASA, requested much higher accuracies over most of the globe.

The Laboratory began an experimental broadcast at 60 kc/s, WWVB, in 1956. Although the radiated power was only 2 watts, this did meet the needs of some specialized users by offering higher precision over shorter measuring periods. For precise measurement, however, 60-kc/s transmission is effectively limited to the continental United States.

In April 1960, the Laboratory began broadcasting with another experimental station, WWVL, at 20 kc/s. WWVL was located in the mountains near Boulder, Colorado. With a radiated power of only 15 watts, it was received as far away as New Zealand and verified predictions of the NBS Central Radio Propagation Laboratory that 20 kc/s was suitable for stable global transmissions. Since 1961, WWVL and WWVB have been controlling WWV in Maryland and WWVH in Hawaii. The improvement this provided in the frequency control of WWV can be seen in Fig. 1(C).

In 1963, both the 60- and 20-kc/s stations began broadcasting with larger antennas and more powerful transmitters from a new site near Fort Collins, Colorado. The radiated power was increased to about 1 kW for WWVL and to about 7 kW for WWVB. The 60-kc/s transmission includes time signals that will offer a precision ranging from a ten-thousandth to a millionth of a second (depending on distance from the transmitter) which is 10 to 1000 times more stable than the signals from WWV. The WWVL 20-kc/s transmission is being used to extend experimental studies required to provide accurate time signals, clock synchronization, and frequency transmission with very narrow band signals over much of the globe.

Besides the creation and dissemination of standards, another major responsibility of the Radio Standards Laboratory is the international comparison of standards. In the area of frequency standards, this responsibility has been met by comparisons made through propagation data among the Bureau standards, four commercial cesium standards in the United States and one in France, the British standard at the National Physical Laboratory, the Canadian standard at the National Research Council, and the Swiss standard at Neuchâtel.

The performance of these various standards has led to international consideration of redefining the unit of time in terms of an atomic transition. The ephemeris second, the presently accepted astronomically based unit, is now recognized as inadequate for precision measurement, and a change to a definition of the second based on atomic properties will probably follow. The choice of a particular atom and a particular transition, the experimental conditions under which this transition is observed, and the assignment of a particular frequency to this transition, will be based on scientific results of the next few years.

The standard of frequency is unique in two ways: the unit of frequency is directly related to the unit defined for one of the six basic physical quantities (length, mass, time, current, temperature, and luminous intensity) in terms of which the units for all other physical quantities are defined; and it is the one standard disseminated by broadcast.

Usually, the chain of derivation extending from a basic physical quantity is quite lengthy and complex and requires meticulous care in analysis and, usually, dissemination is accomplished through the calibration of interlaboratory standards by the NBS Electronic Calibration Center. Otherwise, the various steps in the development of the atomic frequency standards are representative of the evolution of each national standard of measurement.

Dimensionality of radio measurements

Even those working in electronics seldom realize the number of national standards involved in electromagnetic measurements. Figure 2 illustrates three "dimensions" of this work. The front plane shows the variety of standards required to measure power at various frequencies and magnitudes. Succeeding planes show the various quantities of electromagnetic measurement—each requiring an entirely new family of standards.

One must imagine a fourth dimension to this graph to indicate the various activities required in the development of each standard—research, development, and distribution. Finally, a fifth dimension is involved in that the equipment sometimes must operate in a variety of tem-

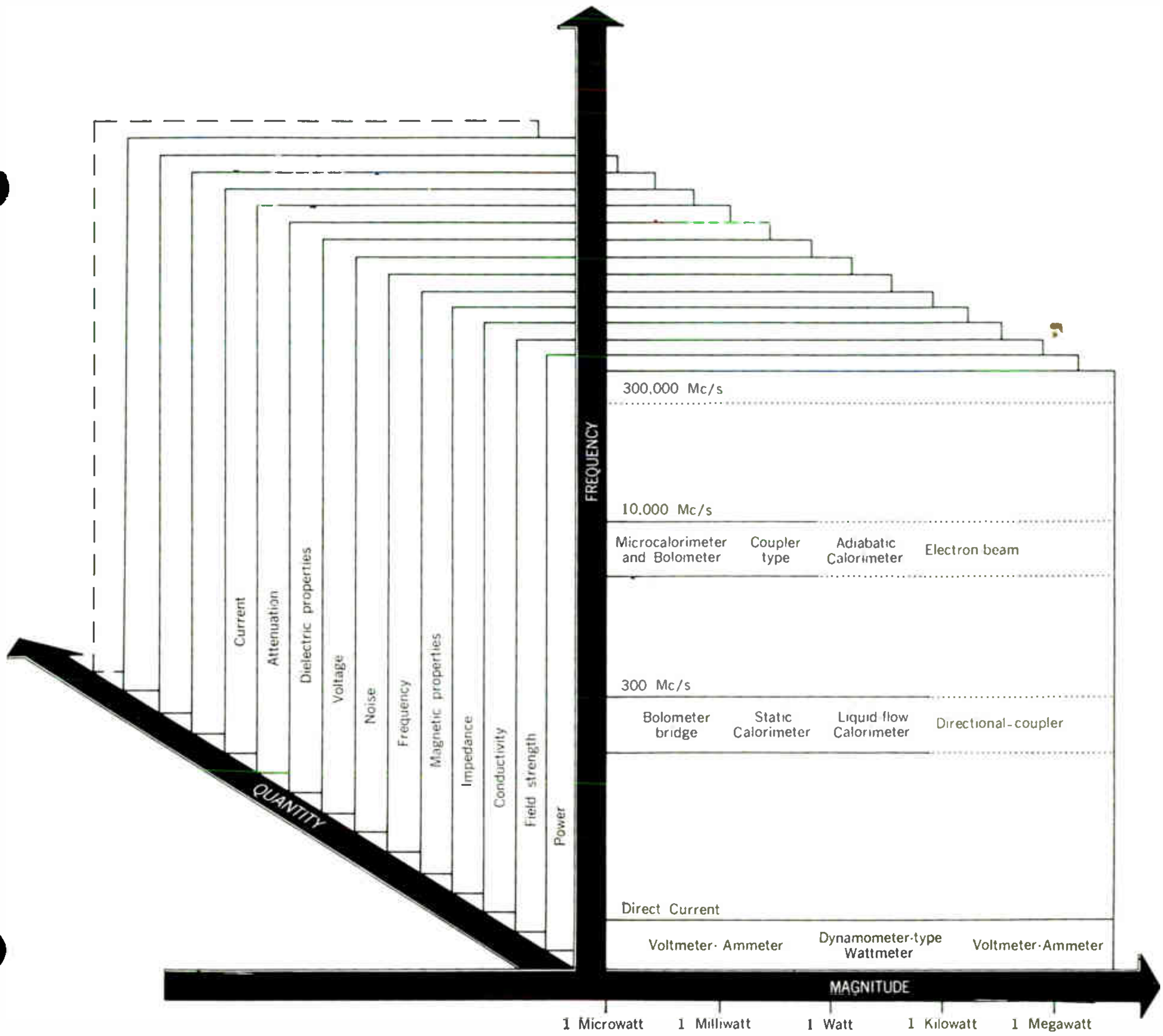


Fig. 2. Three "dimensions" of electromagnetic measurement. Each quantity represented by a plane (power, field strength, etc.) requires a new family of standards

peratures, applied fields, or other environmental parameters.

The scope of this multidimensional space is obviously so big that the Laboratory cannot hope to fill the entire volume. We therefore do our best to recognize key anchor points, and upon these to erect a network to span the various areas to a suitable degree.

Suppose, for example, that we decide that power shall be standardized only at an anchor point near one milliwatt. By standardizing attenuation for all ranges, any value of power can be referred to the one-milliwatt level with a standard attenuator. Thus the need for power standards at all other levels is eliminated.

The general areas of research and engineering at the Radio Standards Laboratory are the development and distribution of frequency standards; studies in the areas of radio and microwave materials, radio plasmas, and microwave physics; the development of high-frequency and microwave standards; and the development and calibration work of the Electronic Calibration Center. A look at work under way and at some of the services available gives an idea of the present status of radio measurement.

Studying basic materials

Materials research at the Laboratory is designed to acquire an understanding of the magnetic (primarily ferrimagnetic), dielectric, and conductive behavior of materials at radio and microwave frequencies, in terms of the atomic constitution and structure of matter. For example, magnetic resonance studies are being conducted to determine the magnetic energy levels, relaxation times, and transition probabilities in paramagnetic and antiferromagnetic crystals.

Specific tools and techniques are developed, such as the RF permittimeter which makes dielectric measurements without electrodes, thus avoiding dielectric and electrode interaction problems and errors.

Probing radio plasmas

Plasma physics is of great interest to the Laboratory because of the potential use of radio methods to characterize plasmas and the potential use of plasmas as radio devices. Measurement of plasma mechanisms is complicated by the number of parameters and variables involved, and by the fact that the numerical values of these quantities cover five to ten orders of magnitude in experimental plasmas.

Because of these problems, the prevalent theories apply to rather idealized plasmas, and often it is impossible to realize physically the assumptions that are used in the theory. Research at the Laboratory is presently limited to phenomena that are associated with the macroscopic properties of plasmas generated in the laboratory, and the goal is reasonably accurate measurement of plasma parameters, variables, and mechanisms.

Exploring millimeter waves

In microwave physics the staff is concerned with the generation, detection, transmission, and measurement of millimeter- and submillimeter-wave power.

Useful devices in industry are already operating at wavelengths as short as one millimeter. Thus, sooner or later the Laboratory is sure to be called upon to make numerous measurements and to provide standards of virtually every quantity that has been of interest at longer wavelengths, especially power, attenuation, and *Q*. Presently the Laboratory has no measurement facilities below 3 millimeters, but we hope during the next few years to have equipment working at wavelengths as short as 0.5 millimeter.

This group is also adapting the Fabry-Perot resonator for use in refractometers, wavemeters, and resonators for masers; is in the final stages of measuring the velocity of light at millimeter wavelengths with a Michelson interferometer, and is using the Stark effect—the splitting of spectral lines by the application of electric fields—to measure dc and low-frequency voltages with very high precision.

Creating microwave and HF standards

In the sections concerned with the creation and evaluation of microwave and high-frequency standards, research is usually aimed directly at a specific measurement application. Two of the basic measurement tools of industry invented by these groups are the RF micropotentiometers for providing accurately known microvoltages at radio frequencies, Fig. 3, and an improved bolometer bridge for measuring microwave power.

Among the national standards and measurement techniques the staff has developed in recent years are systems for measuring attenuation differences up to 120 dB in the 1–300 Mc/s frequency range with an accuracy of ± 0.002 to ± 0.05 dB; and in the 0–50 dB range, at 10 Gc/s, with an accuracy of ± 0.0001 to ± 0.06 dB. These high accuracies are possible at present only as attenuation differences in a system. Measurements on attenuators that must be inserted into the measurement system are more limited in accuracy due to mismatch errors. Reflection coefficients of 0.1 are measured to an accuracy of 1 part in 1000. These are the best values currently available, and are higher than the accuracies offered on a regular calibration basis.

Providing calibration services

NBS working standards for quantities in the high-frequency and microwave regions are established and maintained in the Electronic Calibration Center. Here the Laboratory provides those calibration services which are in sufficient demand to justify the development of instrumentation. Special calibrations not available through the Center can sometimes be arranged, but these

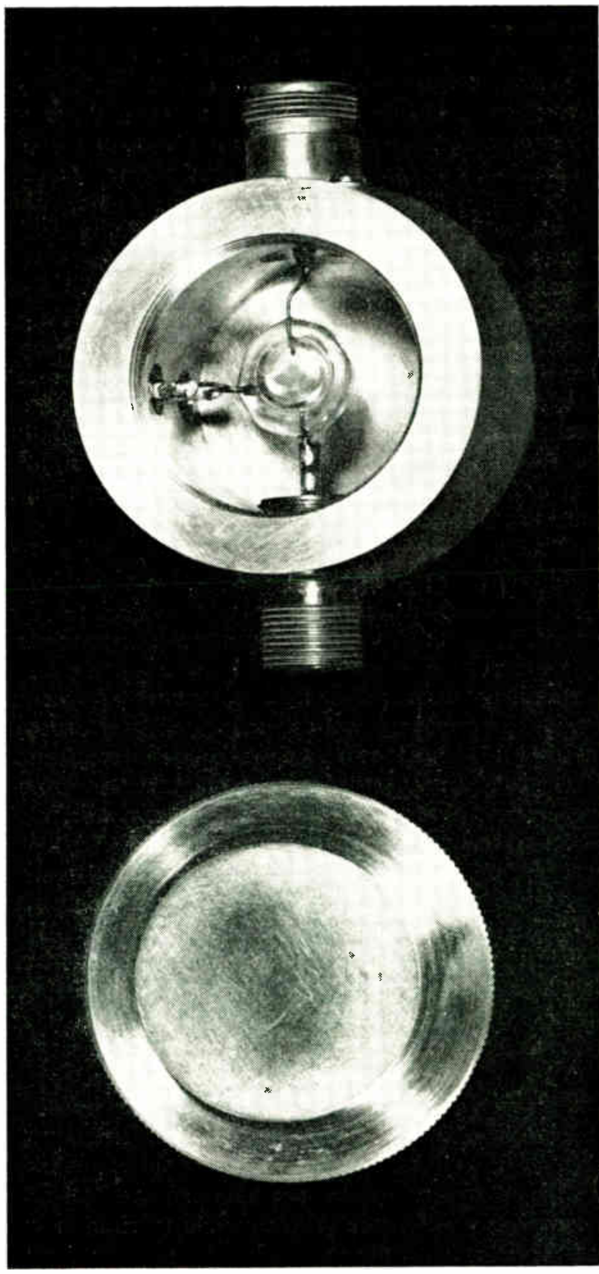


Fig. 3. Micropotentiometer operates on a simple principle a known current is fed into a known very low resistance (one or more milliohms), and the potential drop across the resistance gives a voltage that can be precisely calibrated. Primary purpose is to provide accurate microvolts for checking standard-voltage generators or for use directly as a standard-voltage generator at all frequencies to 1 Gc/s

may require time-consuming research and thus be quite expensive.

The Electricity Division of NBS, in Washington, D.C. is primarily responsible for standards and calibrations in the low-frequency region (below about 30 kc/s), but the Center also provides the low-frequency calibrations that are in greatest demand.

About half the Center's work load is devoted to the design and construction of the special instrumentation required to perform calibrations at optimum accuracies on a routine basis. It is interesting to note what routine means in this context. Since the Center calibrates interlaboratory standards for the nation's top standards laboratories in terms of the national standards, it is obvious that its shop-level calibrations carry a profound responsibility.

At high frequencies (30 kc/s to 300 Mc/s), the Center is equipped to calibrate standards of voltage, power, impedance, attenuation, and field strength. These standards are at present limited to those designed for continuous-wave measurements and those having coaxial terminals. For most quantities, calibration services are offered at the fixed frequencies of 30, 100, and 300 kc/s; and at 1, 3, 10, 30, 100, and 300 Mc/s. Continuous-frequency coverage is provided where feasible, but such calibration equipment is usually less stable and less accurate than that used at the fixed frequencies.

Microwave calibration facilities are being provided at the Center for the measurement of power, impedence, frequency, attenuation, and noise power. The initial goal is to cover the frequency range from 300 to 40 000 Mc/s for all quantities. For one quantity—the frequency of cavity wavemeters—the Center provides a calibration service to 75 000 Mc/s.

Examples of developments in this area include an improved measurement system for microwave impedance (reflection coefficient) calibrations based on reflectometer principles, and an improved microwave radiometer for use in measuring the noise temperatures of microwave sources.

The calibration workload of the Center, see Fig. 4, shows a dip in man-hours during 1962. This is largely attributable to a more efficient calibration program adopted by the Navy which reduces the number of standards sent to NBS for calibration. The upturn during 1963 is the result of some of the new services being offered by the Center.

Measurement needs of the future

To assist in planning for the future, the Radio Standards Laboratory staff has prepared a set of accuracy charts that summarize the state of the art, including existing national standards and calibration services, its five-year goals in national standards and calibrations, and the approximate present measurement needs of industry.

One example of such a chart is Fig. 5 showing microwave power standards in waveguide systems. It shows that at X band (8.2–12.4 Gc/s) a national standard exists in the neighborhood of 10^{-3} to 10^{-2} watt, to an accuracy of one part in 1000, and that this exceeds most of the present needs at this magnitude and frequency. At lower powers there is a continuing loss of accuracy until it is no better than 10 per cent at 1 microwatt. There is also a loss

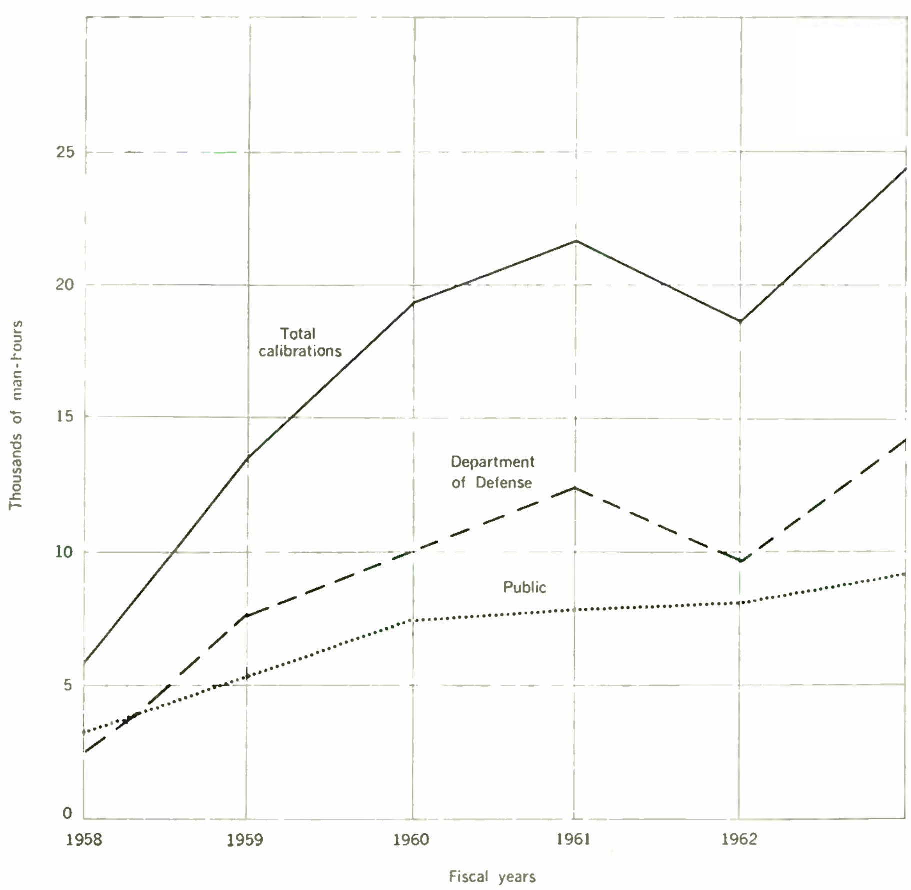


Fig. 4. Calibration man-hours, by fiscal year, of the NBS Electronic Calibration Center. The dips and upturns evident in some of the curves are explained in the text

of accuracy in other frequency bands, and there is no national standard above 10 milliwatts. In this same area, measurements are being made by industry at levels of 1000 or 100 000 watts to accuracies of from 1 to 10 per cent.

The laboratory's five-year objective is to fill in some of these gaps at selected frequencies and at selected power levels, but at somewhat lower accuracies.

Of course, such charts are merely guide lines and are subject to constant review as we continue to receive feedback from industry on present and future requirements. For example, we recently learned of a development program for high-power millimeter-wave tubes that is being undertaken by manufacturers on both coasts. They are in great need of a national standard of millimeter-wave power for rather high peak powers. It takes time for such a development to be incorporated into our program, and we appreciate having as much feedback as possible, as early as possible, and that it be specific and realistic.

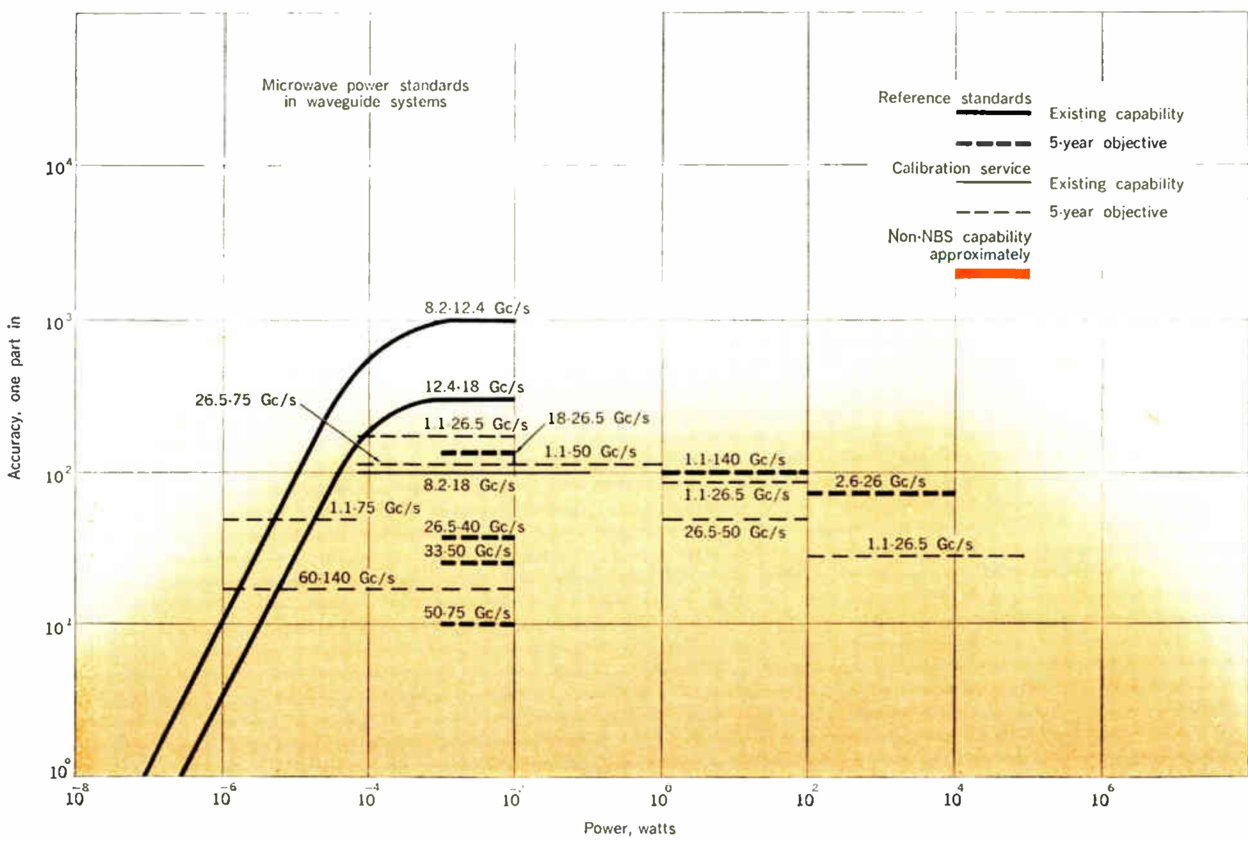
There are other examples which indicate future needs being created by technological advance. NASA is going to extremely narrow-band operation to reduce the transmitter and transponder power required for tracking and communication with deep-space vehicles. Bandwidths of $\frac{1}{10}$ c/s at 10^{10} c/s will be in use shortly. Assuming that an automatic frequency control system would be used, for searching and locking, the signal must be maintained at this stability for at least the AFC time constant, which in turn must be large compared to the reciprocal of the system bandwidth. The frequency stability implied in this requirement is of the order of one part in 10^{13} per second. It is fairly clear that NASA will be forced to hydrogen masers to control such signals, and that therefore we should be considering the performance standards of hydrogen masers.

Measurement of the phase of radio and microwave signals is becoming more and more important. Phase measurement has wide application in the electronic scanning of fixed directional antenna arrays and is essential to the ranging of missiles and space vehicles. Linear phase characteristics are essential to communication systems that transmit high information rates.

During August 1962, the Inter-Range Instrumentation Group determined that there is a need for global synchronization of time to the order of microseconds. The maintenance of time to microsecond accuracy over a typically desired interval of one day requires frequency stability to parts in 10^{11}. Here we have to determine whether it is appropriate for NBS to undertake full global distribution of time and frequency and, if so, the Laboratory must determine feasible ways of accomplishing the objective. One method which should be carefully considered is standard frequency broadcasts from satellites.

Most likely, the whole burden of national standards for lasers as communications devices will fall upon the Radio Standards Laboratory and the NBS Central Radio Propagation Laboratory. The latter is undertaking preliminary experiments with a commercial continuous-wave He-Ne laser and is proposing a substantial study of the propagation of laser beams. The Radio Standards Laboratory must provide the measurement standards for

Fig. 5. Accuracy sheet shows existing and proposed national standards and calibration services, and the present measurement needs of industry



lasers as, for example, measurements of the elements of the third-order tensor giving the nonlinear electric polarization of a material resulting from the application of two intense electric fields.

Other laser standards that are likely to be required, and which we are preparing to investigate, are power, spectral purity, directivity, quantum efficiency of mixers and harmonic generators, power dissipating ability, mode determination, modulation, and noise level. During the next five years, the staff plans to consider the use of double heterodyning systems for measuring attenuation, power, or other quantities at laser frequencies, and laser control by lower frequencies through phase or frequency lock.

The effect of quantum electronics upon radio science has grown until now it overshadows almost all of our future planning. In many projects it is the dominant area of study. For example, a group in materials research is working to establish material constants and characteristics that will provide energy level information for solid-state microwave and millimeter-wave applications. Development has begun on an antiferromagnetic resonance spectrometer, and preliminary antiferromagnetic resonance measurements are being made on systems with low Néel temperatures such as $CuSO_4$ and $CoSO_4$ (anhydrous). During the next few years, the group expects to extend these measurements to many more systems such as the double fluorides KMF_3 (M = Mn, Fe, Co, or Ni) and MnTe, MnSe, and MnSb—including those with higher Néel temperatures.

In the area of nonlinear dielectrics, the Laboratory is beginning the development of a measurement technology to determine the material characteristics of ferro, ferri, and antiferroelectrics under a variety of control parameters. Classes of materials must be investigated for special characteristics such as domain structure and relaxation processes, and the investigations and measurement technology must be extended to optical frequencies. Special needs in this area include knowledge of materials sensitive to thermal environments, development of synthesized specimens of controlled structure and composition, and development of optical measurement equipment.

A goal that underlies all of this work is to increase the accuracy and reproducibility provided by our present macroscopic standards by developing standards (such as the atomic beams) based on atomic or molecular phenomena. Therefore we are increasing our studies into the possibility of deriving electromagnetic standards from such phenomena as the Zeeman effect, the Stark effect, Larmor precession, electron–proton resonance, and nuclear magnetic resonance.

Closing the measurement gap

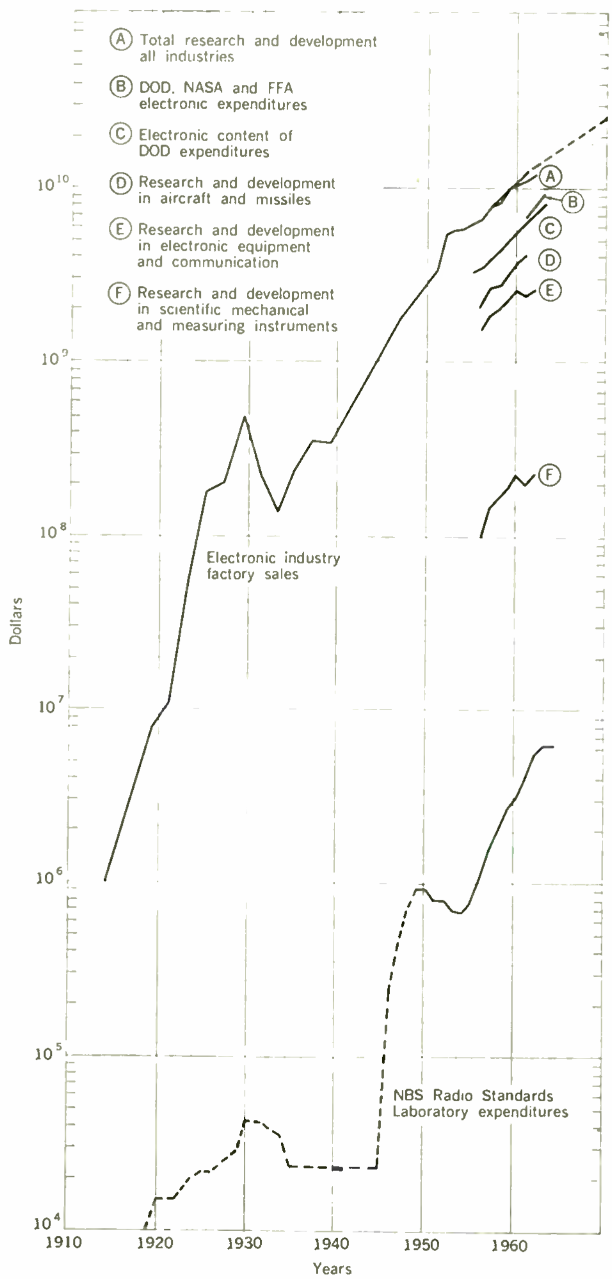
In considering which steps can best help the Radio Standards Laboratory meet its responsibilities, the most obvious is one of selection: the weeding out of measurement needs that can be met by commercial laboratories, and the careful assignment of priority to the work that remains. This is being done, and already a substantial portion of proposed work has been eliminated.

Another possible step is to substitute precision for accuracy. Consider, for example, the cycle of events that has occurred in evolving the length standard. At first the standard of length was to be one ten-millionth of the quadrant of the meridian passing through Paris. Conceptually, this was very satisfying, but in practice it was inconvenient to use. Therefore an arbitrary standard, the meter bar, was adopted because it could be used with much higher precision.

Next the meter bar as a standard was replaced by the wavelength of krypton, at a temperature of the triple point of nitrogen. This is conceptually much more satisfying than the arbitrary meter. It now appears possible that by going to an oscillating laser we will have a standard of length that is much more precise than the krypton wavelength, but its unperturbed value may not be known with such absolute certainty. We might then arbitrarily adopt a laser oscillating under specified conditions as a more convenient standard than the krypton lamp.

The Laboratory is in a similar position with respect to Q factor. We have a bank of standard coils with which

Fig. 6. Financial support for radio standards. Annual sales of the electronic industry and annual expenditures of the Radio Standards Laboratory. (See the Appendix)



other unknown coils can be compared more precisely than their Q factor can be stated in terms of the ratio of energy stored to power dissipated per cycle.

Thus where precision exists with respect to existing arbitrary apparatus, we might quote the results of NBS tests with respect to the "standard of X" as maintained at NBS with, for example, a precision of comparison of perhaps one part in 10^4 and with an accuracy with respect to the international standards of perhaps one part in 10^2.

This would be analogous to the present situation for frequency in which an unknown frequency source can be compared to the national standard of frequency with a precision of one part in 10^{12}, but the accuracy of the national standard of frequency with respect to the internationally accepted standard of time is only one part in 10^9. This anomalous situation occurs because the internationally accepted standard of time (based on astronomical units) is very imprecise, although by definition it is infinitely accurate.

However, the substitution of precision for accuracy and the careful selection of priority do not strike at the heart of the problem, and the program of fundamental development which remains is sobering.

The main curves in Fig. 6 show (1) the annual factory sales of the electronic industry and (2) the annual expenditures of the NBS Radio Standards Laboratory—expenditures which provide the national basis of measurement for this industry. The secondary curves, identified on the figure, show expenditures in related areas.

Figure 7 gives (1) the ratio, since 1946, of the cumulative expenditures of the Radio Standards Laboratory to the cumulative factory sales of the electronics industry, and (2) the ratio of the annual expenditures of the Radio Standards Laboratory to the annual industry sales.

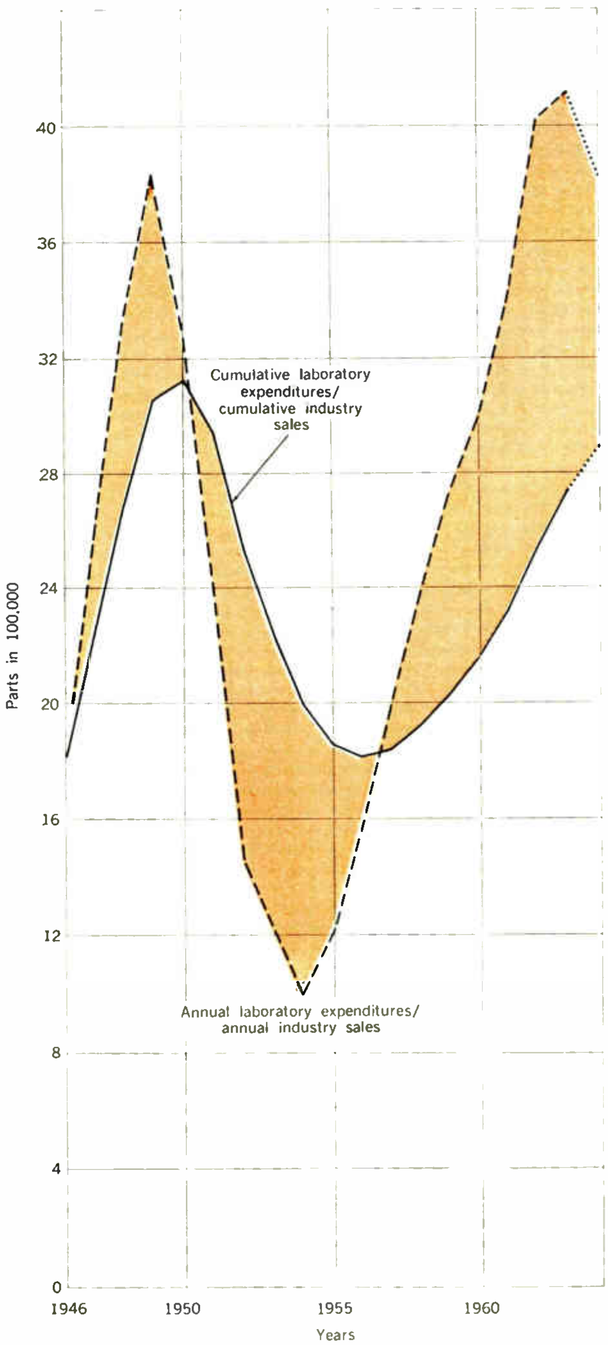
It is clear that there was a period of relatively low support for radio standards, and that in recent years this support has increased. The cumulative effect of the drop in support is seen in the curve which shows cumulative expenditures of the Laboratory relative to industry sales. This curve, which falls below the one showing the relative yearly ratios, indicates the possibility of a backlog of unmet demands.

To explore this situation, the Radio Standards Laboratory has analyzed current needs reported to the Laboratory and has estimated the effort it will take to meet these needs at a rapid but realistic rate of development. The needs in question were made as specific as possible by asking each company or organization involved to define the reason (application) for a reported need, and to estimate the required accuracy at particular points of magnitude and frequency.

These studies indicate a requirement for a significant enlargement in the program of the Radio Standards Laboratory if the very real and expressed needs of the industry are to be met in a realistically determined length of time. Significant enlargement means increases of the order of 30 per cent per year for several years.

This would be a challenge to any organization; it is a particular challenge to a government laboratory devoted to scientific research, whose basic product is knowledge or applied science in which advancement is recorded in the movement of a decimal point.

Fig. 7. Ratios of annual and cumulative expenditures of the Radio Standards Laboratory to annual and cumulative industry sales. (See the Appendix)



APPENDIX

Sources of information for Figs. 6 and 7 are the Electronic Industries Association and the National Science Foundation. The estimate that factory sales of the electronic industry will total $25 billion by 1970 is from R. R. Dockson, "The Electronics Industry and the Dynamic Los Angeles Metropolitan Area," *Growth Pattern Study No. 4*, of the Union Bank, Los Angeles, 1962. The early expenditures of the Radio Standards Laboratory are shown dashed (Fig. 6) since it is difficult to isolate the work in radio standards from other radio research being conducted by NBS at that time. The Laboratory expenditures are expressed in fiscal years while all of the other values are in calendar years; the six month offset between fiscal and calendar values is ignored. The 1964 figure for the Laboratory is an estimate as of September 1, 1963.

Authors

B. M. Oliver (F) was born in Santa Cruz, Calif., on May 27, 1916. He received the B.A. degree in electrical engineering from Stanford University in 1935 and the M.S. degree from the California Institute of Technology, Pasadena, in 1936. Following a year of study in Germany under an exchange scholarship, he returned to the California Institute of Technology where in 1940 he received the Ph.D. degree. From 1939 to 1952 he was employed at the Bell Telephone Laboratories, Murray Hill, N.J., in television research and radar development. He is now vice-president in charge of research and development at the Hewlett-Packard Company, Palo Alto, Calif. Dr. Oliver served as Vice-President of IEEE during 1963 and is a member of the American Astronautical Society.

I. A. Lesk (SM) received the B.Sc. degree in engineering physics from the University of Alberta in Canada in 1948. He pursued graduate work in electrical engineering at the University of Illinois and received the M.S. degree in 1949 and the Ph.D. degree in 1951. He held several positions with the General Electric Company, including consultant in semiconductor devices and techniques, manager of the microdevices study unit of the Semiconductor Products Department, and engineer in the solid-state subsection of GE's Electronics Laboratory. He has been with Motorola since 1961 where his present position is manager of the Basic Physical Studies Department. He is a member of the American Physical Society, Sigma Xi, and Eta Kappa Nu.

C. B. Ackerman received the B.A. degree in physics at Nebraska Wesleyan University in 1948, and the M.A. and Ph.D. degrees in physics at the University of Nebraska in 1950 and 1953, respectively. He joined Motorola's Semiconductor Products Division in 1953. He has worked on high-frequency alloy and surface-barrier transistors, as well as surface studies and evaluation of heat-treatment effects on germanium. He is now manager, alloy power transistor development, and is responsible for development of new and improved power transistor types and the application of postalloy diffusion techniques to the production of diffused-base transistors. He is a member of the American Physical Society and Sigma Xi.

W. E. Taylor attended Purdue University and was awarded the B.S. degree in metallurgical engineering in 1942 and the Ph.D. degree in metallurgical engineering in 1950. While associated with Oak Ridge National Laboratory he undertook solid-state research in metals. He has taught metallurgy at Purdue University and the University of Tennessee. He formerly held the position of manager of material processes at Motorola's Semiconductor Products Division, where he is now manager of materials and microwave devices. For two years he was a professor at Michigan State University's Department of Metallurgical Engineering. He is a member of AIME and the American Physical Society.

J. C. Haenichen (A) attended Massachusetts Institute of Technology and received the B.S. degree in electrical engineering in 1958 and the M.S. degree in electrical engineering in 1959. He joined Motorola in 1959, where he has worked on the development of high-frequency silicon planar transistors for amplifier and switching applications, as well as original device design and process development of silicon mesa and planar transistors. In his present position as manager of new silicon device operations, he is responsible for the development and pilot production of all new devices whose feasibility and profitability have been established. Mr. Haenichen is a member of Tau Beta Pi and Eta Kappa Nu.

W. C. Davis (*below*) received the B.Ch.E. from Rensselaer Polytechnic Institute in 1950. At Sylvania and CBS Laboratories he worked on the development of black-and-white and color television tubes, and power transistors, respectively. He joined Motorola's Semiconductor Products Division in 1960, and at present is product manager for silicon controlled rectifiers.

G. B. Finn received the M.S. degree in physics from the University of Notre Dame in 1950. He has done considerable work in solar cells, silicon rectifiers, and germanium and silicon materials at Sylvania Electric Products, Silicon Corp. of America, Sarkes-Tarzian, Inc., and International Rectifier Corp. He joined Motorola in 1961 and is now manager of operations for diodes and rectifiers.

Alfred N. Goldsmith (F, L), noted radio, motion picture, and television inventor, devoted most of his early years to teaching at the College of the City of New York after receiving the B.S. degree there in 1907. He later received the Ph.D. degree from Columbia University in 1911. With the formation of RCA in 1919, he became director of research and later vice-president. He has been an independent consultant since 1933. Among other notable achievements, his work led to the first commercial radio with built-in speaker, and to the first commercial color television tube. A cofounder of IRE in 1912, Dr. Goldsmith served as President for 1 year, Secretary for 10, Editor and Editor Emeritus for 49, and Director for all 50 years of IRE's existence. He is now Editor Emeritus and Director Emeritus of IEEE and holds two of its major awards, the Medal of Honor and the Founders Award. Among many other honors and awards, he is a Fellow of six societies, an Eminent Member of Eta Kappa Nu, and a Life Member of the New York Medico-Surgical Society.

Wright H. Huntley, Jr. (M) was born in Loma Linda, Calif., on November 5, 1932. He received the A.B. degree in management engineering from Claremont Men's College and the B.S. degree in electrical engineering from Stanford University in 1958. From 1950 to 1954 he was on active duty in the U.S. Air Force as technical instructor in air-borne radar and electronic warfare. In 1955 he was employed by the Naval Ordnance Laboratory, Corona, Calif., in development of missile fuze systems. He has been with Stanford Electronics Laboratories since 1956, and is now research associate in the Systems Technique Laboratory. His activities have included design and development of scanning microwave antenna arrays, research in high-speed color display techniques, and electronic warfare subsystem research and development. He is now investigating possible applications of coherent light to aerospace problems.

J. J. W. Brown (SM) received the B.S. degree in electrical engineering from Purdue University in 1940. Following graduation, he joined the General Electric Company's test program. In 1941 he was assigned to the Aeronautics and Marine Engineering Department, and worked successively on servo and fire control systems, as liaison engineer to the MIT Radiation Laboratory, and as a design engineer on computers. Among other positions at General Electric, he was manager of materials handling and test equipment engineering and manager of the direct conversion projects operation. He is now manager of the power systems engineering operation. He is a member of Eta Kappa Nu, Tau Beta Pi, Sigma Xi, and the Instrument Society of America.

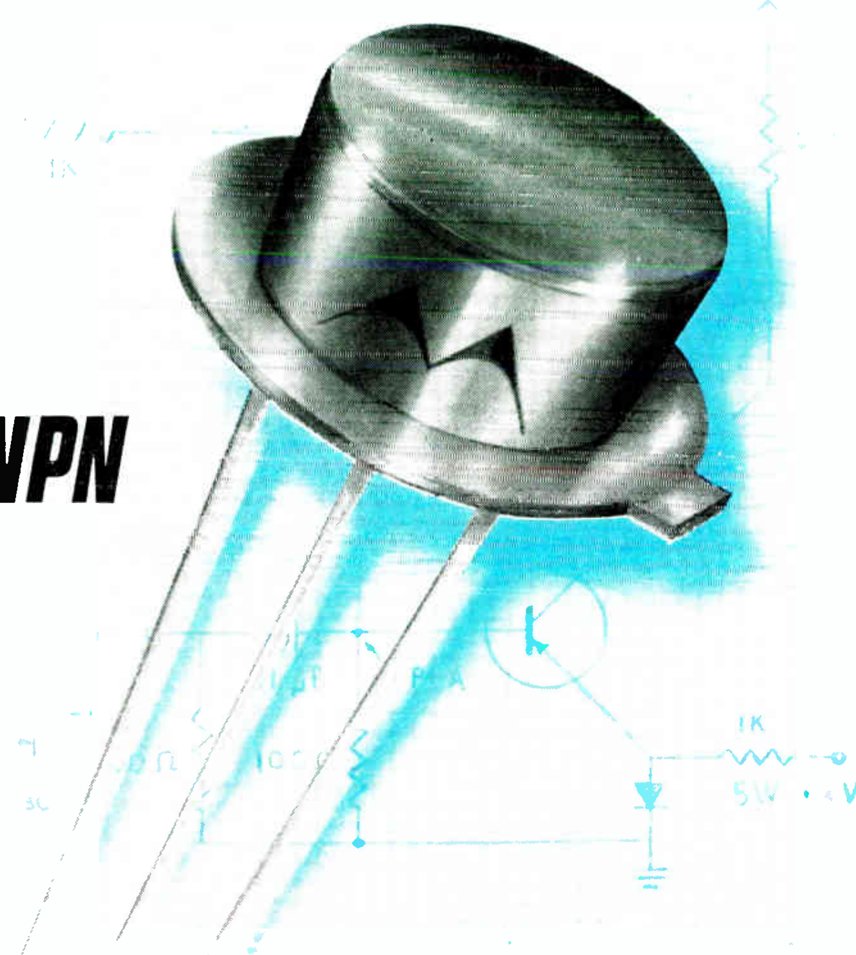
E. M. Hunter (F, L) received the B.S. degree in 1926 and E.E. degree in 1930 from Worcester Polytechnic Institute, and the M.S. degree in electrical engineering from Union College in 1931. He joined the General Electric Company in 1925. He has had a number of managerial assignments in electric utility application engineering operations. His present position, that of manager of power transmission engineering in the power systems engineering operation, includes responsibility for ac transmission, high-voltage dc transmission, and the administration of the transmission laboratory at Project EHV in Pittsfield, Mass. Mr. Hunter is a member of Tau Beta Pi, Sigma Xi, NEMA, CIGRE, and the International Electrotechnical Commission.

John M. Richardson (SM) was born in Rock Island, Ill., on September 5, 1921. He received the B.A. degree in physics from the University of Colorado in 1942 and the M.A. and Ph.D. degrees in physics from Harvard University in 1947 and 1951, respectively. He served in the U.S. Naval Reserve from 1943 to 1946 on the staff of various electronics officer training schools. He was subsequently employed by the Denver Research Institute. Since 1952 he has been with the National Bureau of Standards. His work there has been in microwave physics, including microwave spectroscopy and interferometry, as well as the physics of ionized gases. His present position is chief of the Radio Standards Laboratory. He is a Fellow of the American Physical Society, Fellow of the American Association for the Advancement of Science, member of Commission I of the International Scientific Radio Union, and member of Sigma Xi.

James F. Brockman was born in Hong Kong, China, on November 9, 1924, and came to the United States in 1929. He received the B.A. degree from Yale University, New Haven, Conn., in 1949. Mr. Brockman joined the Boulder Laboratories of the National Bureau of Standards as an information specialist in the Technical Information Office. Since 1961 he has been assigned to the Bureau's Radio Standards Laboratory. He is at present teaching a course in technical writing in the graduate school of the NBS Boulder Laboratories, and is serving as the executive secretary of the 1964 Conference on Precision Electromagnetic Measurements, jointly sponsored by IEEE and NBS.

If You're Specifying Motorola *Annular* Types...

You're Getting The Best PNP and NPN Silicon Transistor Value!



THE *Annular* PROCESS GIVES YOU:

HIGHER VOLTAGE | **LOWER LEAKAGE CURRENT** | **IMPROVED RELIABILITY**

Motorola supplies the following annular transistor types . . . available immediately from distributor stocks:

NPN ANNULAR TYPES

2N697	2N707A	2N834	2N1630	2N2220	2N2330	2N2538	2N2958
2N706	2N708	2N835	2N1711	2N2221	2N2331	2N2539	2N2959
2N706A	2N718A	2N914	2N2217	2N2222	2N2481	2N2540	2N3115
2N706B	2N744	2N956	2N2218	2N2256	2N2501	2N2951	2N3116
2N707	2N753	2N1420	2N2219	2N2257	2N2537	2N2952	

PNP ANNULAR TYPES

2N722	2N1131	2N1132B	2N2837	2N2904A	2N2906	2N2907A	2N3135
2N869	2N1132	2N2800	2N2838	2N2905	2N2906A	2N3133	2N3136
2N955	2N1132A	2N2801	2N2904	2N2905A	2N2907	2N3134	

Whether you're purchasing silicon transistors for current production or buying devices for advanced system applications, you get extra value when you specify ANNULAR transistors.

"new leader in Total Silicon Technology"

MOTOROLA Semiconductor Products Inc.

BOX 955 • PHOENIX, ARIZONA • A SUBSIDIARY OF MOTOROLA INC. 123-074

Focal points

industry
education
government

Quiet sun years begin—international cooperation makes program possible

We are in a new age of exploration of our environment—pushing at frontiers under, on, and above the ground of which the explorers of other ages did not even dream. Drilling below the ocean depths, mapping the Antarctic continent, exploring the upper atmosphere and space with direct probes, all activities of the past decade, have had one important manifestation that affects the world in more than a physical sense. They have given birth to, and in turn have depended on, international cooperation on an unprecedented scale.

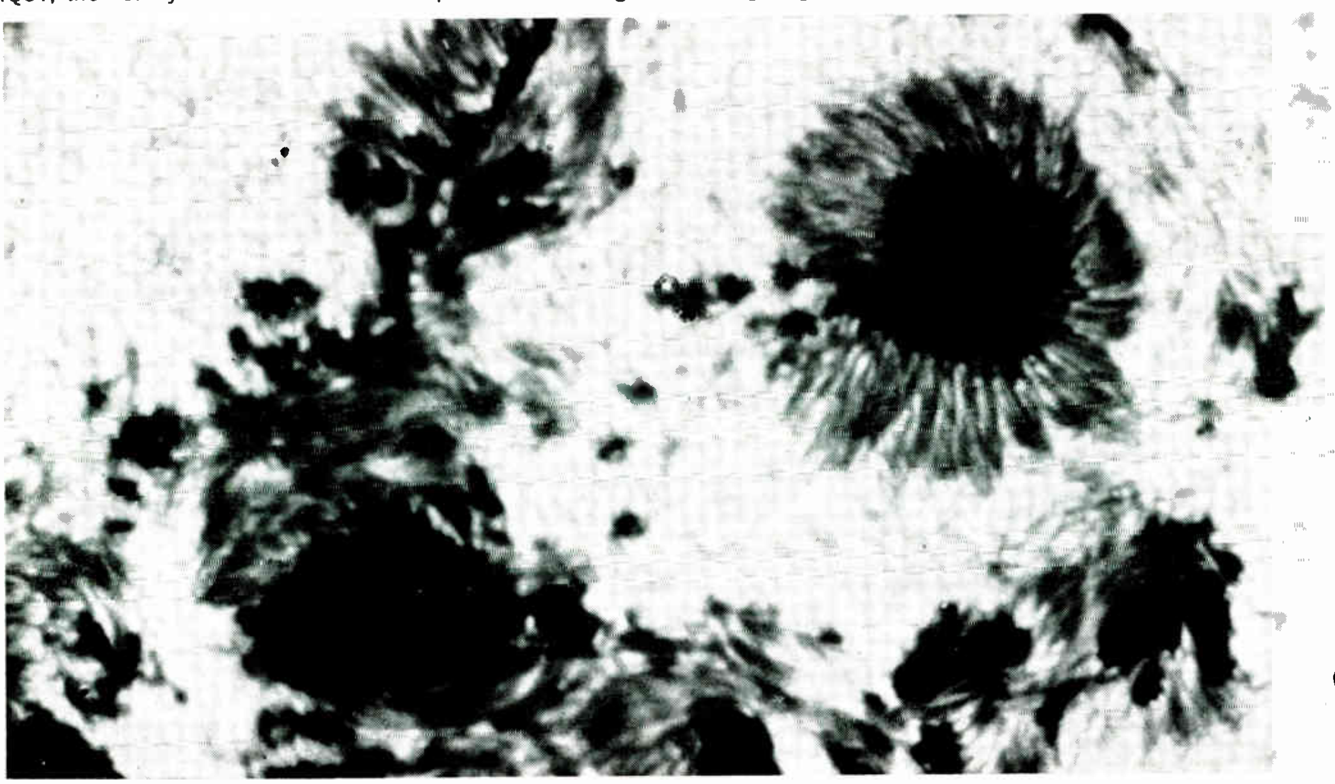
The most recent formal international program of exploration is called the International Years of the Quiet Sun, abbreviated IQSY. It will operate during the two-year interval of January 1, 1964, to December 31, 1965, which includes the expected time of minimum of the 11-year cycle of sunspot numbers—a period of low solar activity.

The IQSY program is entirely one of basic science. It will be worth the cost if the only result proves to be an increased understanding of the universe. But it will be surprising if unforeseen practical benefits do not result also, as has been the case with all large programs of basic research in the past.

IQSY is an outgrowth of its opposite program, the International Geophysical Year (IGY), which was itself the largest international program of exploration ever undertaken. The IGY was a comprehensive examination of the earth, its atmosphere, and its spatial environment, during a peak of the sunspot cycle characterized by unusually *high* solar activity; the observations were made from July 1, 1957, through December 31, 1958. The wide scope of its efforts, which involved scientists of 66 nations, made possible the collection and analysis of an unprecedented body of scientific data.

Twenty to thirty thousand scientists in the cooperating countries took part, operating from some 4000 scientific stations. One of the most important contributing factors to the success of the IGY was the concept of synoptic observations—those made by the same

Active group of sun spots photographed from a balloon at 80000 feet. Though such sun spots are expected to be rare during the IQSY, their study will be all the more important in leading to an undistorted description of solar-terrestrial relationships. The spot group shown in this NSF photo caused major disturbances in long-range radio communications and a brilliant aurora



techniques at the same time from a number of places to give worldwide pictures which had never been available before. Synoptic observations were made possible by the agreement among all the scientists and laboratories involved that data would be exchanged and made available through a system of World Data Centers. In addition, the effort to secure observations in many fields at once on particular days agreed to in advance resulted in learning interrelationships that had not been previously known.

Most of the fields of study involved phenomena which occurred in response to activity on the sun, and it was the interrelationships among these phenomena which were so revealing. For example, studies in the fields of solar activity, aurora, ionospheric absorption, and geomagnetism all together enabled us to spell out the nature of the phenomenon of polar cap absorption (PCA) which can occur following a very large solar flare.

The very advantage of large solar activity resulted, however, in an overlap of events which often made it difficult to disentangle the exact sequence of cause and effect. In an interval when the sun's disk is covered with active regions at all times, regions which are always "flaring" to some extent, it becomes very difficult to know which flare or subflare is responsible for a particular variation in the geomagnetic field. Furthermore, the ionosphere and the earth's magnetic field never get a chance during sunspot maximum to subside back to an undisturbed state before the next disturbance occurs. Thus measures during the IGY itself did not show the full range of terrestrial effects that might occur in response to solar variations. We never got down to where the zero point is.

Development of IQSY. In an attempt to overcome these difficulties the idea began to grow, about the beginning of 1960, that an extensive program at the time of sunspot minimum would be a useful supplement to the IGY for those fields in which the solar variation was important. IQSY was planned through a series of conferences and discussions on the international scientific scene to include activities in most of the IGY fields, but to omit such fields as oceanography and seismology, which are not markedly affected by the solar cycle.

IQSY has developed, not as a miniature IGY, but as a full program that can take advantage of the opportunities for studying solar–terrestrial relationships at the minimum of the sunspot cycle. In a number of areas it will use techniques developed since IGY: in instrumentation, data handling, high-altitude ballooning, and sophisticated space probing.

Each of the more than 60 countries involved in IQSY has planned its own program coordinated in consultation with the other countries at a series of international meetings spaced about a year apart. The overall program took final shape at the last of these meetings, in Rome, in March 1963. Working groups in the individual disciplines met and hammered out the necessary compromises to make an overall international program on which everyone could agree. The working groups' decisions were presented as resolutions before a plenary session of the international IQSY Committee, which examined them for potential conflicts. The final program is contained in a series of reports of the national programs appearing in the publication *IQSY Notes*, and in a series of instruction manuals for the individual disciplines. The *Notes* and the manuals are issued by the IQSY Committee whose executive offices are in London, and are available to scientists in the United States through the U.S. Committee for the IQSY, a committee of the National Academy of Sciences.

The Program. The United States program for IQSY consists of researches in the fields of meteorology, geomagnetism, aurora, air glow, ionospheric physics, radio astronomy, solar activity, the interplanetary medium, cosmic rays, trapped radiation, and aeronomy. Emphasis will be placed on solar mechanisms; determining the state of the interplanetary medium during solar minimum; mapping the earth's radiation zone to establish its configuration and density at minimum; observing solar events and the transit through the interplanetary medium of the solar plasmoids and the interaction of the plasmoids with the geomagnetosphere; observing at magnetically conjugate points on the earth the auroral, ionospheric, geomagnetic, and hydromagnetic consequences of such interactions; determining the energy content of the solar ionizing radiations that influence the aeronomy of the middle atmosphere; studying the winds and circulation of the ionospheric regions; determining the basic photochemical character of the middle atmosphere and ionosphere in its least disturbed condition; and undertaking such programs as studies of the low-energy portion of the galactic cosmic-ray spectrum that are best done during times of solar quiet. Also included will be the completion of certain network synoptic programs of aurora, geomagnetism, ionospheric physics, and cosmic rays throughout the present solar cycle, continuing what was done for IGY and since.

To accomplish these objectives there will be a solar patrol that includes optical flare patrol, radio patrol, and satellite observations. Work in geomagnetism will involve the operation of standard observatories, including those in the Antarctic, and satellite and space probe observations. Networks of all-sky auroral cameras, visual observations, spectrometer and photometer observations, and air glow observations will be active, including operations in the Antarctic and in Greenland. Ionosphere observations include a vertical incidence network, a radio noise network, a riometer network, and several whistler networks covering both very low and extremely low frequencies. Cosmic-ray work includes the operation of a chain of neutron monitors for lower-energy cosmic rays and meson telescopes for the harder component of the flux.

Special opportunities in solar–terrestrial relationships will be pursued by means of X-ray and ultraviolet telescopes, particle detectors, and energy analyzers on satellites, as well as by rocket and balloon observations of particle streams entering the upper atmosphere at geomagnetically significant locations. Such observations, along with the data derived from the synoptic networks, will provide information as to the identity, flux, and energy spectra of the particles, their spatial distribution, and their temporal history. Conjugate point observations will be made between various locations in Alaska, Canada, and the northern United States, and locations in Australia, New Zealand, and the Antarctic.

Coordination. Many of the IQSY observations will be made on a continuing or a daily basis, but in some cases this would be too expensive or otherwise impracticable. Temporal coordination of these intermittent projects is accomplished through a program of so-called World Days and World Intervals. These are indicated on the International Geophysical Calendar in a format which was developed for the IGY and later modified. It marks intervals in which observers can expect that their colleagues in other countries and in other disciplines will be making an increased effort to obtain synoptic observations.

Different designations are used for intervals of differing lengths and periodicities. For example, a Regular Geophysical Day occurs each Wednesday throughout the two-year IQSY. Regular World Days are three consecutive days of each month, always Tuesday, Wednesday, and Thursday near the middle of the month. These are intended for experiments which should be made for about 10 per cent of the total number of days throughout the year. The Wednesday that is a Regular World Day and a Regular Geophysical Day is a Priority Day, and there is one each month; on it both weekly and monthly observations would be made. Similarly, there is in each season a Quarterly World Day, and also a World Geophysical Interval consisting of 14 consecutive days intended for intensified programs aimed at the statistics of seasonal variations or the timing of seasonal changes. In addition to these arbitrarily chosen times, the calendar indicates the dates of solar eclipses and meteor showers which may call for special observations.

Certain other special days are not shown on the calendar because they cannot be predicted in advance; they are days of Alerts or Special World Intervals, which are declared by one of several solar–geophysical regional warning centers on the basis of observations of actual or impending solar activity, or solar-related events. Notices of the Alerts and Special World Intervals are distributed by telegram and radio broadcasts and through the meteorological telecommunications network.

World-wide cooperation in the timely exchange of collected data is an important part of the program. The exchange of data that are either raw or just sufficiently calibrated for use by others enables all investigators to have for analysis a wider span of data than they could expect to obtain by their own efforts. Making his data available to others on a timely basis involves some sacrifice on the part of the observer, because it forces him to a relatively short time during which his own observations are exclusively his for analysis and interpretation. That thousands of observers have been willing to join in this world-wide exchange for the good of all is a testament to their selflessness and their devotion to the progress of science.

The World Data Center system, developed for IGY, has remained in operation ever since. It comprises three major centers, World Data Center A in the United States, B in the U.S.S.R., and C having disciplinary components in Japan, Australia, and several western European nations. On a regional basis, original data, either raw or reduced, are forwarded to one of these three centers. Each center then sends copies to the other two, so that each accumulates identical global data. From these three centers or their elements data are supplied upon request, usually on a cost basis, to scientists and scientific institutions from their various regions. In the United States, several institutions and agencies, each responsible for a single discipline, form the total complex of World Data Center A. Coordination, particularly necessary in international exchange, is supplied by the National Academy of Sciences.

Organization. International scientific programs are formal arrangements developed among groups of people who are themselves members of sovereign states. Not all the people are subject to the same sets of laws, or to the same customs or political systems. In view of these differences, the scientists' success in organizing international projects has required great diplomatic skill. Their success has been generally recognized as a pattern of human cooperation to be emulated in other fields.

A few dozen international scientific societies exist that bring together scientists or engineers with common interests. Normally the adherence to such a union is by country, with a national committee in each country. The membership of individuals in the union is through membership on a national committee, or on the recommendation of that committee. (Customs vary somewhat from one union to the next.) Since a number of problems and goals are common to the several unions, they have formed an International Council of Scientific Unions (ICSU), a sort of parental or supervisory body with its own officers and committee structure. United States adherence to any of these international bodies is through the National Academy of Sciences.

IGY was primarily the creation of three of the international scientific unions: the International Scientific Radio Union (URSI), the International Union of Geodesy and Geophysics (IUGG), and the International Astronomical Union (IAU). However, the enterprise involved other unions, notably the International Union of Pure and Applied Physics (IUPAP). Coordination of the IGY program was achieved under a special ICSU committee for the IGY, known as CSAGI (Comité Spécial de l'Année Géophysique Internationale). For the activities after IGY, a continuing Comité International Géophysique (CIG) was established, which in turn established a working group for IQSY and in March 1962, at the first IQSY General Assembly in Paris, the CIGIQSY Committee was formally appointed. This committee, under the chairmanship of Prof. W. J. G. Beynon of the United Kingdom, included representatives of the four scientific unions just mentioned, a reporter appointed by the appropriate scientific union for each discipline, representatives of other ICSU committees and international scientific organizations: the Scientific Committee on Antarctic Research (SCAR), the Committee for Space Research (COSPAR), the International Ursigram and World Days Service (IUWDS), and the World Meteorological Organization (WMO). The latter group is somewhat more governmental in character than the others, being an agency of the United Nations. In addition, regional representatives are chosen to ensure that all areas of the world are adequately represented.

U.S. coordination in the IQSY program is provided by the National Academy of Sciences and the National Science Foundation. The Academy's Geophysics Research Board (GRB), under the chairmanship of Dr. M. A. Tuve, has a Committee on IQSY chaired by Dr. M. A. Pomerantz. Its executive secretary is Stanley Ruttenberg, and its concern is with the international contacts essential in carrying out the program, the planning and balance of the U.S. program, and the coordination of the World Data Centers and data exchange generally.

In the later stages of the IQSY program's development, the Academy sought formal Government endorsement through the National Science Foundation. Dr. A. T. Waterman, then director of the Foundation, obtained authorization for U.S. participation from President Kennedy, who, at the same time, designated the National Science Foundation as the agency to correlate the Federal Government's regular activities that contribute to the program, and to coordinate and to arrange the budget for the additional activities. In carrying out these functions, the Foundation is guided by a panel of advisers from the scientific community. Funding of special IQSY projects is done in the same way as the Foundation's funding of other researches.

The total U.S. contribution to the IQSY is, of course, far larger than the projects funded out of specially designated parts of the Foundation's budget. Work in the broad area of geophysics stimulated by IGY continued through the intervening years. The ongoing programs of many agencies, for example NASA, the Department of Defense, and the Department of Commerce's Weather Bureau and Bureau of Standards, all contribute to IQSY and are taken into account when the U.S. program is presented in detail to the international IQSY Committee. Their volume of work may be likened to the large, invisible volume of an iceberg that is below the water line. The added amounts from specially designated funds for IQSY projects are relatively smaller, and sometimes have the function of the keystone in an arch. They frequently establish a new station that serves to bind already existing stations into a series, or they may set up an experiment which should be carried out with the others to study their interrelationships or, again, experiments or observational programs that require a special interdisciplinary effort for completion.

Looking toward the future. It is, of course, too early to state precisely what new, exciting advances will come out of IQSY. However, we can discern two trends in modern science that are typified by this program. First, interest in international cooperation in science is increasing. Science has always been a cooperative effort characterized by cordial relations across national boundaries, but it is only very recently that tremendous improvement in transportation and communication has enabled people to pool their efforts on such a large scale. Looking at it another way, this pooling of effort can multiply the efficiency of every American scientist. He receives stimulation and information not only from his colleagues in the same laboratory, city, state, or country, but has these benefits from the world-wide body of scientists. Much duplication of effort is saved. Though sending a body of people to an overseas conference involves expense, usually the ideas brought back save larger expenditures that would have been planned in ignorance of other scientific work.

A second trend is the growth of a new area of scientific research—a field without a unique name but beginning to be recognized as an entity. It represents an extension upward of the interests of geophysicists (especially students of the atmosphere) to include the interplanetary medium, planetary atmospheres, even the weather of the solar atmosphere. Interests of many astronomers now extend downward into the earth's atmosphere. This mixing of concepts and methods from fields which were formerly widely divergent has been healthy for the growth of all.

One might, of course, describe the new field of interest as a simple extension of either geophysics or astronomy, but in practice it is more than that. A solar system with all its intricate interactions of parent star, interplanetary medium, magnetic and radiation fields, and solid planets is probably a common phenomenon in space. Nevertheless, the detail with which we can study our particular solar system is so much greater than the detail which we can bring to bear on analogous systems that it becomes a specialized problem within the broad field of astronomy. It is important, but not of overriding importance, in comparison with stellar evolution, the nature of the galaxies, cosmology, and the many subdivisions of these areas which form the main problems of astronomy.

At the same time, the new field is somewhat "far out" to students of the lower atmosphere, oceanography, and the solid-earth branches of geophysics. All these fields are affected by the sun and especially by variations of the solar output, but as soon as we get much below the level of the absorption of ultraviolet light by ozone, the fluctuations of solar energy input to the lower atmosphere and to the surface are vanishingly small. The main energy fluctuations are in the far ultraviolet, and they affect primarily the upper atmosphere. Readers of this journal will of course recognize that the ionosphere and magnetosphere, the regions of the atmosphere which are so critical to radio communications, are markedly affected by solar variations, so that a radio engineer is more concerned with solar activity than is, for example, an oceanographer.

The activities of which we speak are sometimes called "space research," though that implies that the observations are made from space vehicles rather than from the ground. Ground-based work forms a substantial part of the activities in the field. The term "planetary sciences" has been frequently used; "space physics" and "space science" are other terms. Frequently the terminology is influenced by the traditional academic field out of which the new activity has grown in the local context. In the National Science Foundation responsibility for this general area is in the Program for Solar Terrestrial Research, a part of the Section for Atmospheric Sciences. The coordination of the IQSY is one of the activities of this program office.

We may confidently expect that while reaching into space and understanding more and more of the large-scale environment in which we move, we will, through such activities as the International Years of the Quiet Sun, mature both in knowledge and in our ability to get along with each other on the surface of our small planet.

Robert Fleischer

Coordinator for the IQSY
Program Director for Solar Terrestrial Research
National Science Foundation
Washington, D.C.

Approaching transonic commercial air travel propels all-weather landing systems to the fore

All-weather landing systems—with optimum operational capability in conditions of low and zero visibility—have been the goal, through the years, of the aviation industry. The expected increase in subsonic and transonic jet air travel in the next decade—and the complexity of safely and efficiently controlling and terminating air traffic according to its destination schedule—has tinged the problem with a sense of urgency. Diversion of flights because of weather conditions to alternate airports in the United States alone last year cost domestic carriers an estimated $60 million. In Europe, and especially in England, where greater low-visibility exposure exists, the hard-won time-saving potential of new very-high-speed aircraft is perhaps under graver threat than elsewhere.

Here, in the United States, high priority is being given to the early development of such a system. The Federal Aviation Agency (FAA) at its National

Positions Open

The following positions of interest to IEEE members have been reported as open. Apply in writing, addressing reply to address given or to Box Number, c/o IEEE Spectrum, Advertising Department, 72 West 45th St., New York, N.Y. 10036.

Overseas. Robert College, in Istanbul, Turkey, presents a challenge in education where East meets West. An opportunity to contribute significantly to the development of a young republic is available to specialists in engineering, business administration and economics, the sciences, the humanities, and English as a foreign language. Graduate degrees required. Address inquiries to Miss Shirley Osmun, Personnel Officer, Robert College, Bebek Post Box 8, Istanbul, Turkey; with copy to the Near East College Association, 548 Fifth Avenue, New York 36, New York.

The Department of Electrical Engineering at the City College of the City University of New York seeks staff in all academic ranks; Professor, Associate Professor, Assistant Professor, Instructor and Lecturer. For Professional appointments the Doctor's Degree is required. Opportunities available for combined research and teaching at graduate and undergraduate level. Salaries commensurate with qualifications and experience. Apply in confidence to Prof. H. Taub. Chairman, E.E. Dept., The City College, New York, N.Y. 10031

Electrical Maintenance Superintendent. B.S. Degree in E.E., with minimum of 10 years' experience in electrical maintenance. To take charge of electrical preventive maintenance program and crew. Also, to be responsible for all electrical engineering in integrated pulp and paper mill currently involved in $21,000.000 expansion program. Salary open, commensurate with qualifications and experience. Excellent fringes and benefits. Write, giving resume of education and experience, to. William E. Fish, Personnel Manager, The Chesapeake Corporation of Virginia, West Point, Virginia.

Positions Wanted

Address replies to Box Number given, c/o IEEE Spectrum, Advertising Department, 72 West 45th St., New York 36, N.Y.

Ph.D., E.E., extensive teaching, research & design background in A.C. & D.C. machines, des. outstand. opportunity in indust. or univ. Box 8000.

Electric utility distribution and transmission superintendent, 17 years' experience, returning from foreign assignment, seeks position anywhere U.S. or Canada. Available immediately. Box 8001.

Advertising/P.R. Manager. Highly diversified experience in electronics and industrial products. Know trade publications and all media; ability to develop and execute sales-producing ideas and marketing plans; able budget and product administrator. Work with sales, engineering & top management. Large corporate experience. Box 8002.

Phase III can be attained is adequate roll-out guidance once the aircraft has touched down. Two major functions are involved: (1) all-weather surveillance information that must be available to the controller, and (2) feeding guidance information to the pilot so that he may safely bring his aircraft from runway to ramp in conditions of no visibility.

FAA studies second generation system. The ILS–radio-altimeter flare-out system, which is the heart of the first generation AWLS, bears some inherent limitations that the FAA hopes to overcome through a second generation AWLS. The new system will utilize two ground stations to transmit elevation and azimuth beam guidance information into the approach zone to provide air-derived guidance data to any equipped aircraft. These same ground stations will receive radar reflections from approaching aircraft to provide ground-derived guidance data for monitoring or for backup precision approach radar (PAR) capability. Integrated into the system is a precision distance-measuring technique, utilizing an air-borne interrogator–decoder and a ground transponder. The aircraft is thus in possession of precision angle and distance data —all the guidance information required for the entire approach and landing maneuver.

This ground-scanning technique should prove superior in a number of ways: (1) To provide broader, more flexible approach paths for incoming aircraft (ILS system, in essence, establishes fixed approach slots); (2) To eliminate the transition at low altitude from ILS glide-slope guidance to radio-altimeter guidance. Narrow scanning microwave beams would provide guidance from five to eight miles out, until touch-down. Ground-scanning technique is under development by Airborne Instruments Laboratory, and should be ready for ground testing in about two years.

In addition, the FAA is now evaluating three other systems: (1) Bell Aircraft's GSN-5 system, built around K-band ground-based tracking radar and a ground computer; (2) Regal, developed by Gilfallan and the Bendix Corp., a system combining X-band vertical measuring equipment, distance-measuring equipment, and air-borne flare-out computer; and (3) North American's APN-114, a radio-altimeter type of flare-out system with inertial rate of descent used to augment height signals.

Some human nature problems are anticipated in implementing the all-weather system. Many pilots will at first have reservations about relying on an automatic landing system. But the successful performance of the system will bring so great an advance in flying safety that quick acceptance is likely.

International Space Communication Conference allocates radio frequencies for use in interstellar space

With the signing of the Final Acts, the Geneva Space Radiocommunication Conference, convened by the International Telecommunication Union (ITU), completed its work.

The main task of the Conference, attended by more than 400 delegates from 70 ITU member countries, was the allocation of radio frequencies for outer space activities and the consequent revisions of the *Table of Frequency Allocations* which is the heart of the Radio Regulations, the basic document governing the operation of radio throughout the world. This was last revised by the Geneva Radio Conference of 1959. The allocation of an adequate number of frequencies for outer space has become an urgent task since then because of the rapid growth of activity in space.

The Conference allocated, on a shared or exclusive basis, frequencies totalling 6076.462 Mc/s for the various kinds of space services, 2800 Mc/s of which are for communication satellites on a shared basis with other services. Thus, while at the 1959 Conference only about one per cent of the frequency spectrum was made available for outer space, about 15 per cent has now been made available.

The details of the allocations are shown in the accompanying table of frequency allocations. Where reference is made to Regions, Region 1 comprises roughly Europe, Africa and the Middle East, Region 2 comprises the Americas, and Region 3 comprises Asia and Australasia.

The Conference adopted a number of revisions and additions to other parts of the Radio Regulations, mainly concerned with general rules for the assignment and use of frequencies, notification and recording of frequencies in the Master International Frequency Register, the identification of stations, service documents, terms and definitions,

Table of frequency allocations

Frequency bands	Service
Decametric waves, Kc/s	
15 762–15 768	Space Research, shared
18 030–18 036	Space Research, shared
Metric waves, Mc/s	
30.005–30.010	Space Research and Space (satellite identification), shared
37.75–38.25	Radio Astronomy, shared
73–74.6	Radio Astronomy, exclusive
136–137	Space Research (telemetering and tracking), shared in regions 1 and 3, exclusive in region 2
137–138	Meteorological-Satellite, Space Research (telemetering and tracking), Space (telemetering and tracking), shared
143.6–143.65	Space Research (telemetering and tracking), shared
149.9–150.05	Radionavigation-Satellites, exclusive
267–273	Space (telemetering), shared
Decimetric waves, Mc/s	
399.9–400.05	Radionavigation-Satellites, exclusive
400.05–401	Meteorological-Satellites (maintenance telemetering), Space Research (telemetering and tracking), shared
401–402	Space (telemetering), shared
460–470	Meteorological-Satellites, shared
1400–1427	Radio Astronomy, exclusive
1427–1429	Space (telecommand), shared
1525–1535	Space (telemetering), shared
1535–1540	Space (telemetering), exclusive
1660–1670	Meteorological-Satellites, shared
1664.4–1668.4	Radio Astronomy, shared
1690–1700	Meteorological-Satellites, shared
1700–1710	Space Research (telemetering and tracking), shared
1770–1790	Meteorological-Satellites, shared
2290–2300	Space Research (telemetering and tracking in deep space), shared
2690–2700	Radio Astronomy, exclusive
Centimetric waves	
3400–4200 Mc/s	Communication-Satellites (satellite-to-earth), shared
4400–4700	Communication-Satellites (satellite-to-earth), shared
4990–5000	Radio Astronomy, shared in regions 1 and 3, exclusive in region 2
5250–5255	Space Research, shared
5670–5725	Space Research (deep space), shared
5725–5850	Communication-Satellites (earth-to-satellite), only in region 1 and shared
5850–5925	Communication-Satellites (earth-to-satellite), only in regions 1 and 3 and shared
5925–6425	Communication-Satellites (earth-to-satellite), shared in all regions
7250–7300	Communication-Satellites (satellite-to-earth), exclusive
7300–7750	Communication-Satellites, shared
7900–7975	Communication-Satellites (earth-to-satellite), shared
7975–8025	Communication-Satellites (earth-to-satellite), exclusive
8025–8400	Communication-Satellites (earth-to-satellite), shared
8400–8500	Space Research, shared in regions 1 and 3, exclusive in region 2
10.68–10.7 Gc/s	Radio Astronomy, exclusive
14.3–14.4	Radionavigation-Satellites, exclusive
15.25–15.35	Space Research, exclusive
15.35–15.4	Radio Astronomy, exclusive
19.3–19.4	Radio Astronomy, exclusive
Millimetric waves, Gc/s	
31–31.3	Space Research, shared
31.3–31.5	Radio Astronomy, exclusive
31.5–31.8	Space Research, shared in regions 1 and 3, exclusive in region 2
31.8–32.3	Space Research, shared
33–33.4	Radio Astronomy, only in region 1 and shared
34.2–35.2	Space Research, shared

and special rules relating to particular services. These revisions and additions were required to make provision for the space services. In addition, the Conference accepted a number of important resolutions and recommendations. One of these deals with the future action to be taken by the ITU in the light of future developn.ents in space radio communications.

One of the most important resolutions concerns space vehicles in distress or in an emergency. It notes that the frequency of 20 007 kc/s had been set aside by the Conference for this purpose and states that temporarily the distress signal used by ships or aircraft—(SOS) in raido telegraphy and MAYDAY in radio telephony—should also be used by spacecraft.

Another recommendation, addressed to the International Radio Consultative Committee (CCIR), emphasizes that "... the use of satellite transmissions for direct reception by the general public of sound and television broadcasts may be possible in the future" and urges the CCIR to expedite its studies on technical feasibility of broadcasting from satellites. Thus an important step has been taken toward the future possibility of the general public's receiving radio and television programs direct from satellites.

A further recommendation called on the forthcoming ITU Aeronautical Conference to provide high-frequency channels (bands between 2850 and 22 000 kc/s) for communications for routine flights of transport aerospace vehicles flying between points of the earth' surface both within and beyond the major part of the atmosphere.

Finally, a recommendation was adopted recognizing "... that all Members and Associate Members of the Union have an interest in and right to an equitable and rational use of frequency bands allocated for space communications" and recommending to all ITU Members and Associate Member States ". . . that the utilization and exploitation of the frequency spectrum for space communication be subject to international agreements based on principles of justice and equity permitting the use and sharing of allocated frequency bands in the mutual interest of all nations."

The Conference is considered to have reached agreement on its difficult problems largely because of the high degree of harmony and cooperation that prevailed.

ENGINEERING SOCIETIES PERSONNEL SERVICE, INC.

(Agency)

If you are an employer and are interested in a listing under our "Men Available" column, under the New York office section, write to the New York office, listing the applicant's number, and a copy of his résumé will be mailed to you immediately. In the event that said applicant becomes employed by you, a placement fee in the amount of 2 per cent of the first year's salary will be charged to you. The above does not apply to our Chicago and San Francisco "Men Available" listings.

If you are an applicant interested in any of our "Positions Available" listings, and are not registered, you may apply by letter or résumé and mail to the office nearest your place of residence, with the understanding that should you secure a position as a result of these listings you will pay the regular employment fee. Upon receipt of your application a copy of our placement fee agreement, which you agree to sign and return immediately, will be mailed to you by our office. In sending applications be sure to list the key and job number.

New York	Chicago	San Francisco
8 West 40 Street	29 East Madison St.	88 First St.

Positions Available

January 1964

DEVELOPMENT ENGINEER, electrical graduate, with a minimum of 5 years' experience in transistor HF pulse and digital circuit design (nanosecond range). Broad background preferred encompassing vacuum-tube and analog techniques. Equal opportunity employer. L.I., N.Y. W-4014(b)

SUPERVISOR, BSEE, with 5 to 15 years' managerial experience with electromechanical background and emphasis on electronic circuitry, as applied to production machinery, for a producer of precision multicolor printing processes. Will be responsible for recommendation, design, and application of electrical equipment to company products, assist on installation problems, and advise on plant electrical problems. $10,000–$12,000 plus profit-sharing retirement plan and liberal insurance program. Conn. W-4011.

PRODUCT ENGINEER, BSEE or BSME; with 2 to 5 years' experience in production of electromechanical and/or electronic equipment. Good working knowledge of fairly simple solid-state circuitry. Will see that manufacturing holds to engineering specifications. To $10,400. Fee negotiable. Metropolitan N.J. area. W-4005.

ELECTRICAL TRANSMISSION ENGINEER, BSEE, with 5 to 10 years' experience in transmission line design, engineering and construction. Salary open. Apply by letter including salary requirements. Mass. W-3998(a).

JUNIOR ENGINEERS, BS in EE or ME, with 0 to 2 years' general engineering experience, to enter training program with corporate staff engineering group. Limited travel. To $8000. New York, N.Y. W-3988.

ELECTROCHEMIST, Ph.D. or equivalent desired, with knowledge of and competence in electrode kinetics from an experimental point of view, for investigations of electrode reactions in nonaqueous media from a fundamental point of view. Considerable independence in planning and executing of the work. Salary open. Mass. W-3980.

TECHNICAL WRITER, engineering degree, with experience in preparing texts for proposals and publications, preferably relating to the electronic component field. Will write proposals for submission to customers concerning design capabilities, functional application and manufacturing delivery capabilities for a manufacturer of electrical connectors. Will assemble detailed technical information to be written in proposal form in support of bids to customers in the OEM, military and aviation markets. Salary open. Conn. W-3961.

ENGINEERS. (a) Research Engineer, degree in electrical engineering or physics, with 2 to 5 years' experience. Work will include studies of the behavior of dielectrics at high frequencies, setting up instrumentation laboratory in connection with these studies, and design of microwave components. Salary open. (b) Sales Engineer Trainees, electrical or mechanical degree, plus component selling experience to OEM accounts. Indefinite training period at headquarters plant followed by territorial assignment somewhere in U.S. To $10,000 to start. Company pays fees. Headquarters, Central Penna. W-3957.

DESIGN ENGINEER, Capacitors, BSEE or equivalent product design experience in capacitor field. Experience in the design and product development of high-voltage capacitors; will be involved in design and development of capacitors using dielectrics such as rolled kraft paper, mylar, teflon, isomica and bentonite clay film capacitors. From $10,000. Company pays fee. Central Penna. W-3956.

SENIOR PROJECT ENGINEER, Cutouts, BSEE, with several years' experience in cutout design, for design and development of distribution cutouts and fuse links. $9000–$12,000 plus annual cash bonus, profit-sharing retirement plan, major medical group insurance; interview and moving expenses paid. Missouri. W-3953.

SALES ENGINEERS. (a) Senior Sales Engineer, BSEE, math or physics. Minimum of 3 years' selling experience in electronics research and development to government. $10,000–$14,000. (b) Electrical Engineer, young, interested in sales work. Actual sales experience not necessary and/or will take non-degree sales engineer with 5 or more years' experience in command control sales. $10,000–$14,000. (c) Advanced Programs Command and Control—Marketing. Past experience in command and control electronic systems, forces and weapons, for Army, Air Force, and Navy. MSEE required. $13,000–$16,500. East. W-3924.

SALES ENGINEER, electrical graduate, with electrical equipment sales experience, to sell high-voltage power capacitors, large and small, through manufacturers' representatives. Considerable traveling. $8000–$10,000. Headquarters, New England. W-3899.

EDITORIAL PERSONNEL. (a) Assistant Editor, BSEE, to procure and edit articles on theory and application of information systems, control systems, digital data, etc. $9000–$11,000. (b) Assistant Editor, BSEE, background in electronics with a flair for reporting and writing technical articles in this field. $7500–$10,000. New York, N.Y. W-3882.

ELECTRONICS ENGINEER, at least a BS in EE or an ME, experienced in the design of electronic-electrical-mechanical control devices with some supervisory experience. Must be design and engineering application oriented rather than production or industrial engineering. Should be interested in taking on administrative-management responsibilities. $15,000–$20,000. Mass. W-3870.

ELECTRICAL ENGINEER with at least 5 years' experience in field or regulated power supplies, to design (both theoretical and practical) new models with specified characteristics and costs. Test prototypes and prepare reports on same and supervise others doing similar work. Must be versatile. Small but growing firm. To $12,000. Central N.J. W-3869.

DEVELOPMENT ENGINEER, graduate electrical, mechanical or chemical, with about 10 years' experience in design and analysis of control systems and components in process or steam power fields, to design and analyze electrical control systems for power boilers and boiler turbine units for subcritical and supercritical steam pressure. Analyze steam dynamic characteristics using field test results and also computer simulation studies, $13,000. Conn. W-3863.

DESIGN ENGINEER, BSEE, with at least 3 to 6 years' experience in the design and development of pulse system packages (modulators), charging chokes and pulse transformers for application in the radar field. Some overall knowledge of the field of pulse forming networks. Salary open. Central Penna. W-3852.

SALES ENGINEER, Inertial Instruments Products, with experience in inertial guidance systems components for application and sales of velocity meters, electro-static accelerometers, gyros and possibly attitude reference platforms; also design or systems engineering integration experience. Will develop overall sales strategy related to a specific product line; will act as company technical representative to potential customers; coordinate inputs from field sales representatives with broad management objectives. $13,000–$16,000. Upstate New York. W-3851.

ASSISTANT CHIEF ELECTRICAL ENGINEER, graduate, with minimum of 10 to 15 years' experience in transmission and distribution for large firm of consulting engineers. Should have design, estimating, construction, and office experience to do all proposal and contract on this type of work. $15,000–$18,000. East. W-3846.

SENIOR ELECTRONIC PROCESS DEVELOPMENT ENGINEER, electrical engineer, physicist, etc., with inventive ability and flair for the unusual approach and solution to problems; successful record of unique accomplishments in electrical–electronics fields; experience in optics, computing circuitry, control circuitry and/or process control desirable. Will be responsible for designing and developing electrical and electronic systems to control manufacturing processes—e.g. (1) make measurements of small angles and dimensions in micro-inch range and (2) develop high-speed sizing-gaging control without "contacting" product. To $15,000. Mass. W-3825.

HIGH VOLTAGE POWER SUPPLIES

15 to 30 KV

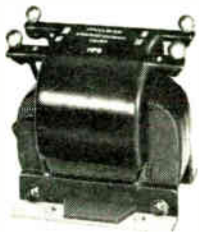
CONTINUOUSLY VARIABLE REGULATED DC POWER SUPPLY WITH FOCUS VOLTAGE TAP.
Regulation better than 0.5% at 1ma. Ripple less than 0.1%. Highly filtered. Variable focus tap 4-6 KV for use with flying spot tubes. Model RP-30 with meter $375. Less meter $325.

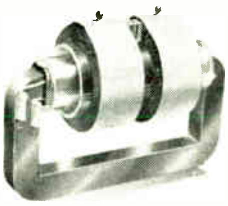
Send for catalog showing many other models.

HIGH VOLTAGE TRANSFORMERS

7 KV For Transistorized power supplies such as full wave DC to DC convertor. Input 28V. 7 KV at 0.5ma. Completely encapsulated 2″ x 2¾″ x 1¾″. MODEL T-7A $24.00.

8 KV Input 110 V 60cy. Output 8 KV RMS 10ma. Suitable for use in single-end or doubler circuit in air or oil. 5″ x 5″ x 4½″. MODEL HP-8 $30.00





44 KV Input 110 V 60cy. Output 44 KV RMS. 10ma. Can be used single-ended or in 120 KV doubler circuit 15½ x 11 x 7. Use in oil. MODEL HV-44 $125.

Many other High Voltage and Step-up Transformers are available.

SEND FOR COMPLETE CATALOG.

SPELLMAN

HIGH VOLTAGE CO., INC.
1930 ADEE AVENUE, BRONX 69, N.Y.
(212) KI 7-0306

Low noise, microvolt signal processing

reaching out where any noise can be a signal

Instruments developed for infrared technology created this line—suitable wherever low noise characteristics are vital. Example: IRI's microvoltmeter indicates $2.2 + 10^{-10}$V (per cycle @ 5KC).

Over 50 catalog units include:

amplifiers
pre-amps
calibrators
integrators
microvoltmeters

Get special combination tech bulletin.

IR INDUSTRIES INC

INFRARED INDUSTRIES, INC.
Radiation Electronics Division
SANTA BARBARA, CALIF. (805) 684-4181

Cut costs—save valuable space with these...

SUB-MINIATURE "U, UA, and UB" AIR VARIABLES

Precision machined for high reliability—exceptional mechanical stability!

- **HIGH "Q"—GREATER THAN 1500 AT 1 MC!**
- **HIGH TORQUE... 2½ TO 10 INCH OUNCES!**
- **LOW TEMPERATURE COEFFICIENT—PLUS 45 ± 15 PPM/°C!**

Cut costs—improve performance—save valuable space with these sub-miniature air variable capacitors! Type "U" requires less than 0.2 square inch for chassis or panel mounting—Types "UA" and "UB" require less than 0.23! No special tools required for installation—slotted rotor shaft accommodates large screwdriver. Rotors and stators precision machined from one piece of solid brass—provide outstanding mechanical stability. Units offer high "Q" (greater than 1500 at 1 mc.); low temperature coefficient; provide absolute freedom from moisture entrapment found in trimmer capacitors of the enclosed or solid dielectric type.

All metal parts are silver-plated—ceramic is steatite Grade L-4 or better. Exceptionally uniform delta C and voltage characteristics . . . voltage breakdown ratings available to 1300 volts DC.

Three fast, easy mounting styles— Single Section types available in: "Loc-Tab", Printed Circuit and Two-Hole—Differential and Butterfly types available only in Printed Circuit mounting styles. Tuner (coil-capacitor) assemblies available in production quantities to your specifications.

Detailed Components Catalog Available—Write for your free copy today on company letterhead.

Capacitors • Tube Sockets • Connectors • Pilot Lights • Insulators • Knobs and Dials • Inductors • Hardware

E. F. JOHNSON CO.
7414 Tenth Ave., S. W. • Waseca, Minn.

Correspondence

On models for reality—Philosophy, including the more specialized philosophy of science, is not a particularly familiar topic with engineers. The practicing engineer (civil, mechanical, electrical, etc.) is likely to be a pragmatist who is not directly concerned with questions of basic research (or metaphysics or epistemology). He has little need for justifying what he does in terms of a philosophy—the obvious short- and long-run economic needs of society provide justification enough for a pragmatist. When an engineer turns to basic research, he becomes a scientist with a useful tool (i.e., engineering know-how) and forthwith joins with others in the physical and life sciences who seek to clarify basic questions. Sometimes the converting engineer needs a philosophic hand-hold in order to make the transition gracefully. The purpose of this note is to offer such a crutch—but I hasten to warn that the one to be discussed does not fall into the conventional pattern.

Current philosophy as it pertains to physical science seems to have been most influenced by the successes of Einstein's theory and the often elegant logic of Bertrand Russell. I wish to describe an earlier and much less popular philosophy as formulated by Herbert Spencer (who was an engineer), T. H. Huxley, and others. Strangely, Spencer is scarcely even mentioned in many books on the philosophy of science most appropriate to the physical sciences.

Spencer championed the notion of thoroughgoing scientific agnosticism—that nothing is provable or understandable. Indeed, this is a forlorn philosophy and it is apparent why a strong following did not develop, especially after these notions spread to morality, ethics, and religion. A typical situation given in support of Spencer's philosophy is the limitlessness of matter—one can never really discover the logical limit of smallness on the one hand or of vastness on the other.

It is intended here to rephrase scientific agnosticism in a way that is somewhat more palatable, and perhaps even more than trivially different from that due to Spencer. Plenty of room will be left for separate opinion in metaphysics and religion, which the Spencerian dogma appears to abolish as inconsequential. Before proceeding, however, it is well to point out that what satisfies the life scientist in the way of a philosophy may not be embraced by a physical scientist. The former prefers to base his concepts on Darwin's theory; the latter on mathematical logic. Perhaps this difference in point of view is due to preoccupation in the life sciences with evolving structures, whereas evolution as such has little or no bearing on problems of interest to the physical scientist. When one tries to build physical simulations of phenomena from the life sciences, the two points of view must be reconciled. Perhaps the following discussion can aid in this.

Let a phenomenon P be represented in symbolic terms, where symbols may be prose, logical statements, geometric structures, mathematical equations, and so forth. Phenomenon P is explained by truth T, which can be expressed in an unlimited sequence of terms as

$$T = T_0 + T_1 + T_3 + \ldots + T_n + \ldots \quad (1)$$

where we suppose that T_0 is the principal statement of T, T_1 is the first-order correction term to T_0, T_2 is the second-order correction term, and so forth. The independent variables in T are left unspecified for convenience—actually, everything that happens in the universe may have an effect on the single phenomenon represented by T (as in Lewin's field theory).

Man, through several senses, observes P and seeks to discover T. He attempts to construct model M in symbolic terms hoping that, at least for his requirements

$$M \approx T \quad (2)$$

Model M has a sequence of terms (albeit, many may be zero) so that

$$T \approx M = M_0 + M_1 + M_2 + \ldots + M_n + \ldots \quad (3)$$

Let us suppose that, by stroke of good fortune, a scientist finds a few of the leading terms in M which are also those in T. Then

$$T \approx M = T_0 + T_1 + T_2 + \ldots + T_q + M_{q+1} + M_{q+2} + \ldots \quad (4)$$

in which event a model for the truth has been discovered. But caution must be exercised: M is not T, but only

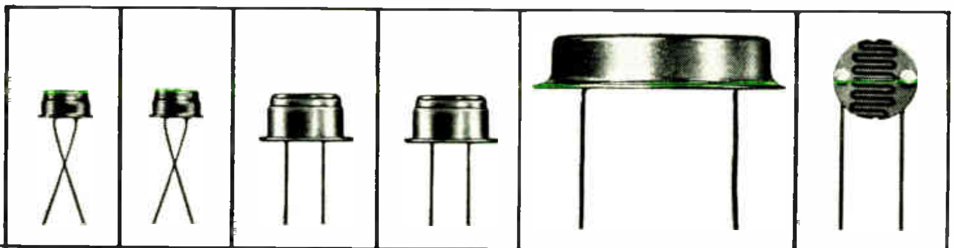
FREE

General Electric photoconductive cells to design engineers for breadboarding work and evaluation testing

Here's a chance to try the new G-E photoconductive cells at *absolutely no cost to you*. We've been telling you, through ads and sales calls, about the long life, ruggedness, high sensitivity and proven reliability of our photoconductive cells. Now we want you to try them. We want you to *prove to yourself* that they will equal or surpass any other cadmium sulfide photoconductive device on the market. And it won't cost you a cent to do it!

Check the following specifications to see which cell(s) comes closest to meeting your requirements. Keep in mind that on most types, when it comes to production orders, these "fixed" specifications can frequently be varied to match your exact need, often at only a slight price premium.

(Photocells shown actual size)



GE TYPE NUMBER	A33	A35	B46	B425	B1035	Y-1136(‡)
Wave length of maximum spectral response	5550 ±700Å	5500 ±700Å	6100 ±600Å	6100 ±600Å	6100 ±500Å	6100 ±600Å
Maximum power dissipation	75 mw	75 mw	250 mw	250 mw (500 mw on request)	300 mw cont. 600 mw int.	200 mw
Maximum applied voltage	30 v	50 v	60 v	250 v	350 v	250 v
Resistance @ 2 ft-c. Resistance @ 100 ft-c.	6000Ω 340Ω	12000Ω 650 Ω	1000Ω 100 Ω	9000Ω 480 Ω	4500Ω 220 Ω	9000Ω 480 Ω
I would like to have the number of samples indicated (Write in box)						

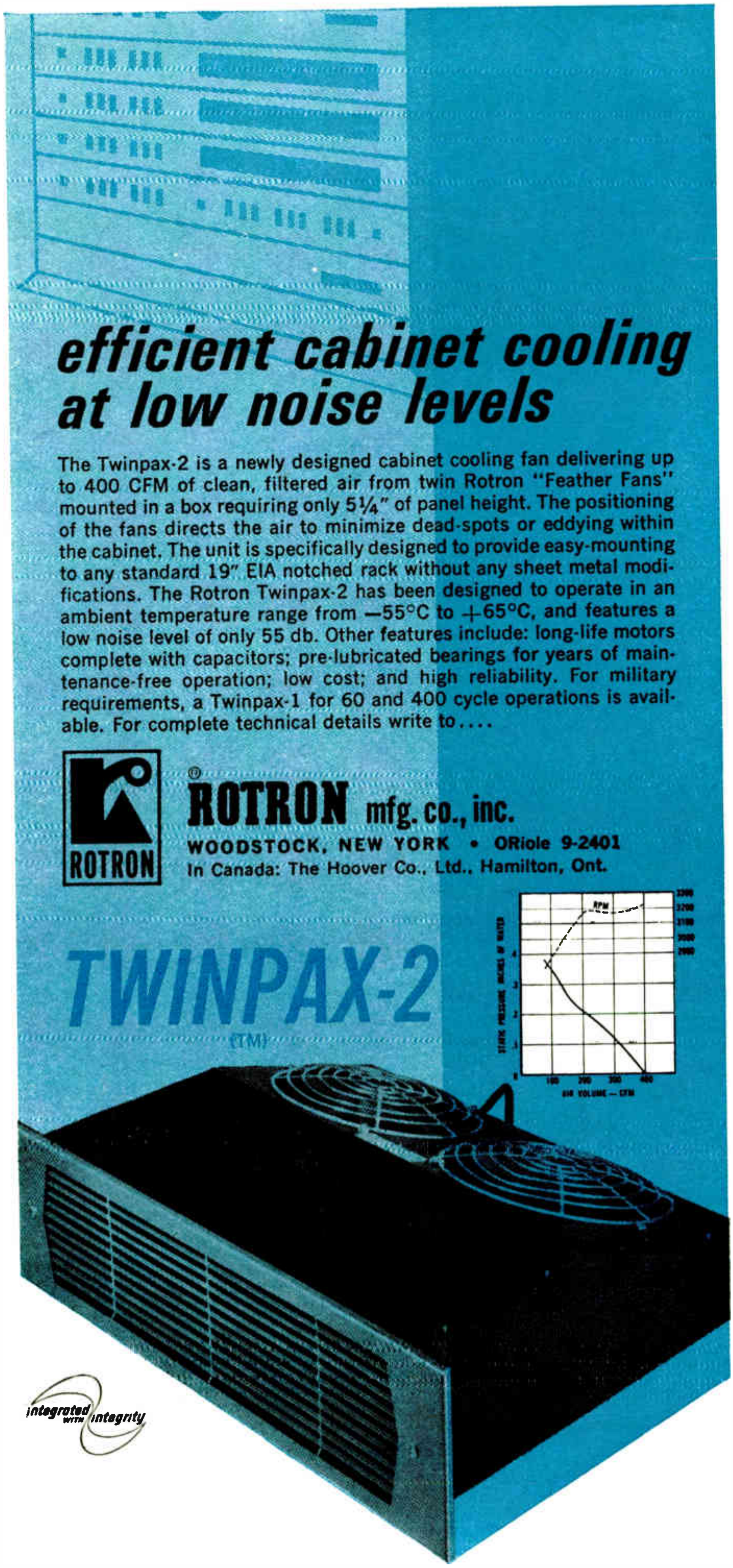
Here's how to get your free photoconductive cell(s):

(1) Tear out this ad, **(2)** Indicate the type of photoconductive cell(s) you are interested in evaluating, **(3)** Specify the number of cells desired*, **(4)** Mail the ad, along with a note written on your company letterhead giving your name, title, indication of the specific application involved, and an estimate of present and potential usage for samples requested, to: General Electric Company, TIPS Box 7000C, Owensboro, Kentucky. That's all there is to it. Why not tear out the ad right now!

Progress Is Our Most Important Product

GENERAL ELECTRIC

‡Now in initial development stage; sample supply extremely limited until 2nd Quarter.
*Offer is subject to withdrawal without notice, and arbitrary sample limits may be imposed at the discretion of General Electric Company.



approximates T. M represents a fictitious world invented by the scientist in order to explain reality. Many scientists have been fooled into mistaking M for T, especially if M consists of a compact mathematical statement.

Along with a successful $M \approx T$ approximation, a model based on causal factors is often provided. This model is generally identical with the entire sequence ΣM_k. Let us next ask the question: How many symbolic models M based on arbitrary causal factors exist whose first q terms agree?, i.e., if

$$T \approx M_1 = T_0 + T_2 + \ldots + T_q + M_{q+1} + M_{q+2} + \ldots$$

$$T \approx M_2 = T_0 + T_2 + \ldots + T_q + M_{q+1}' + M_{q+2}' + \ldots$$

$$T \approx M_3 = T_0 + T_2 + \ldots + T_q + M_{q+1}'' + M_{q+2}'' + \ldots \quad (5)$$

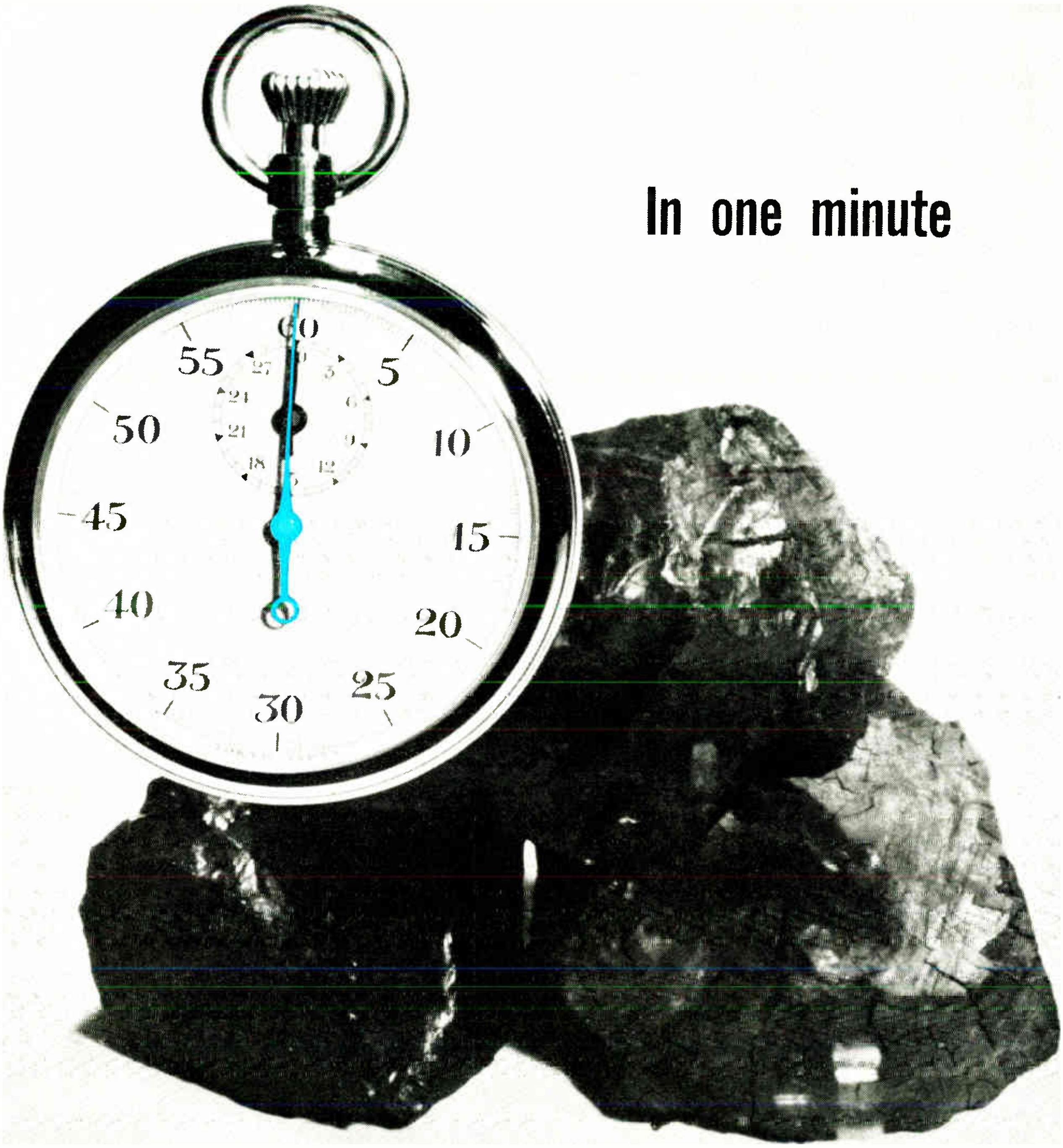
and if each approximation conjures up a different set of causal factors, then which model and associated set of causal factors is the correct one?

From the foregoing it is evident that any one phenomenon can be approximated in terms of an unknown number of models M and associated sets of causal factors. No single explanation can therefore be expected to be absolutely correct.

The task of the scientist is apparent from this argument. He must seek ever more accurate approximations to reality. In the process he may be able to rule out certain models with their indicated systems of causal forces in preference to others. In the course of his work, the scientist should be willing to modify his theories of causality, even drastically if indicated (which, unfortunately, sometimes involves emotional factors when "pet" theories are attacked). The frustrating thing about all this is that the process is never ending; existence of numerous and competing sets of causal factors must always be recognized. In fact, more causal systems may remain unknown than known! We can at least take comfort in the apparent never-ending need for (paid) scientists.

As an aside, the nature of an applied scientist can perhaps be clarified at this point. He seeks to adapt a known model to a current need. In this process, he does not obtain a more accurate approximation to reality except, perhaps, inadvertently.

Some phenomena have terms in the T series which decrease very rapidly. In such cases, only a few of the leading terms need be discovered in order to acquire a relatively good model. Such is


In one minute

the situation in classical physics where equations are simple and straightforward (although this hardly applies in modern particle physics). I think this situation has misled many people into endowing mathematics with unusual powers to reveal the truth; the most frequently taught philosophy of science seems to repeat this oversimplification. If a scientist develops an excellent model, he becomes like God in the imaginary universe represented by his construct. But he does not thereby acquire absolute knowledge in the real world—no more, perhaps, than the historian or the politician.

Most phenomena have T series which are not adequately represented without the use of many terms. This situation is characteristic of the life sciences. Neat mathematical formulas involving a highly limited number of variables are rarely apparent. It is no wonder that, in the life sciences, mathematics is not especially useful! This may have caused many life scientists to actively avoid the use of mathematics in their work; rather, they tend to pure experimentalism using verbal arguments and, when the bulk of data so indicates, the convenience of orderly processing by means of digital computers. The physical scientist scoffs at this attitude, which only serves to underscore his misunderstanding. It is almost absolutely safe to say that the important problems in the life sciences will never be explained with expressions as "simple" as those deriving from Einstein's general gravitational theory or the Schroedinger equation for irregular crystal lattices.

On the other hand, the life scientist is making a mistake in not recognizing the value of quantitative mathematical models for representing elementary parts of a complex system. The process of direct simulation, for example, provides a calculus by means of which elementary constituents may be combined to form a "computer" to solve equations which may not even be known. Model making of the direct simulation kind may serve to provide quantitative explanations for phenomena which are too complex to be clarified by means of mathematics alone, yet which may require liberal use of mathematics in order to implement the construction.

We have argued upon the assumption that the approximating model M contains the first few terms of the truth series T. The situation is not this simple; for the existence of an approximation to reality does not imply content of any particular term or terms in T. In short, the individual terms in T are as unknowable as T itself. So we leave the problem at this point—perhaps the dilemma can be resolved through astrology. But in any event, I hope the discussion has softened the implications of scientific agnosticism by suggesting that truth may at least be achievable in the limit. I also hope that the notion of approximation serves to suggest a bridge with which different philosophies may be reconciled.

John L. Stewart
Santa Rita Technology, Inc.
Menlo Park, Calif.

A definition of hot electrons. It seems appropriate to point out that the terms "hot electron diode" and "hot electron triode" as applied to a metal-semiconductor diode and a semiconductor–metal-semiconductor triode, respectively, are confusing, inasmuch as they suggest that other devices, in particular p-n junction devices, are not hot electron devices. The purpose of this note is to emphasize that conventional p-n semiconductor diodes and triodes are *also* hot electron (or hole) devices and to suggest that other more suitable terms be used to apply to the metal-semiconductor devices.

The term "hot electrons" was evidently coined by Shockley[1] to describe electrons in the conduction band of germanium that had been elevated to energies well above the bottom of the conduction band by a strong electric field. This does not imply, however, that electrons very near the bottom of the conduction band cannot also be hot electrons under suitable conditions. The proper reference level is the Fermi level and the correct definition of hot electrons must be *those electrons associated with an excess density over the density corresponding to thermodynamic equilibrium with the lattice*. The thermal equilibrium density is the product of the density of states in the material and the Fermi-Dirac distribution function for electrons at the appropriate lattice temperature. There are several ways of generating hot electrons (or holes) in various materials, as indicated in this list:

(1) Photoexcitation in any material
(2) Quantum mechanical tunneling, as in Esaki diodes and metal-insulator-metal structures
(3) Minority-carrier injection across a forward-biased p-n junction
(4) High-field acceleration in nonmetallic materials, as in avalanche

breakdown in reverse-biased p-n junctions

(5) Schottky emission over a metal-semiconductor junction that is forward biased.

Any device utilizing *any* of these phenomena could be called a "hot-electron" (or in some cases "hot-hole") device, but such an adjectival phrase is not particularly definitive.

It is suggested that metal-semiconductor diodes be called M-S diodes, and that semiconductor–metal-semiconductor triodes be called S-M-S triodes or metal-base transistors.[2]

Donovan V. Geppert
Stanford Research Institute
Menlo Park, Calif.

1. Shockley, W., "Hot Electrons in Germanium and Ohm's Law," *Bell System Technical J.*, vol. 30, Oct. 1951, p. 990.
2. Geppert, D. V., "A Metal-Base Transistor," *Proc. IRE*, vol. 50, June 1962, p. 1527.

Watch your language! My duties as Editor of the IEEE Transactions on Electronic Computers have made me sensitive to a number of solecisms and inaccuracies current in the speech and writing of the members of our profession. I hope that pointing them out may be a small step toward stamping them out. I find especially offensive:

1. The use of "finite" where "nonzero" is intended. Thus, engineers often speak of "a finite probability," just as though there were some other kind. Again, a recent book speaks of "finite-width sampling pulses" on one page and on the next of "finite band-width." One must read with care in order to recognize that the author means in one place "not zero" and in the other "not infinite"!
2. The careless redundancy of "binary bits." Since "bit" is a contraction of "*b*inary dig*it*," the repetition of "binary" is quite unnecessary.
3. "Hopefully." This adverb is enormously abused. For instance, "The signal is hopefully well above the noise." A *signal* cannot do anything "hopefully," or "cheerfully," or "happily." "Hopefully," like these others, is an adverb that may be used properly only to describe the actions of people. One may hope that the signal is well above the noise, but the signal itself is quite indifferent about the matter.

Norman R. Scott
University of Michigan
Ann Arbor, Mich.