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Most people recuperating from an illness are content to read thrillers and dream about trips to exotic places. But engineers are an unusual breed—and Harold Levenstein, consultant in our Advanced Systems Technology Department, illustrated our point by spending his convalescence having fun with an imaginary variable. By the way, we are glad to report that he is back at work.

Graphical Evaluation of Polynomial Functions Of An Imaginary Variable

Among the many curious ways by which mathematicians and their sympathizers have attempted to discover the roots of real polynomials, one of the more interesting is a geometric construction due to Lill, and described by Turnbull[1] in his little book on "Theory of Equations." If we take $P(X) = A_0X^n + \ldots A_n$ as our polynomial, with $A_0 > 0$ and the A_i all real, we can represent it as follows. Draw in connected sequence line segments having lengths $A_0, A_1, \ldots A_n$, with the connecting segments arranged at right angles. The choice of right- or left-hand turn is determined by the sign change of the successive coefficients. Thus, if the coefficients have the same sign turn to the right (clockwise); if they are oppositely signed, draw A_i on the left-hand perpendicular. By way of example refer to Figures 1 and 2 (from Turnbull). Now draw a test trajectory as shown by the dotted line. Each segment of this trajectory is perpendicular to the previous segment, starting where that segment intersected the original trajectory of coefficients. Note that, if one of the original coefficients was zero, a phantom line should be drawn to define its direction for purposes of establishing the intersections. The test trajectory has one less side than the original trajectory.

If we define X_0 as $\tan\theta$, as shown in Figure 1, then it is an elementary exercise to show that the

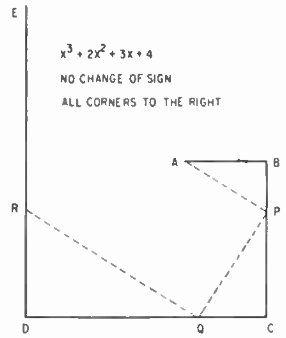

FIGURE 1

distance from R to E corresponds to the remainder when the polynomial is divided by $X - X_0$; if this is zero, X_0 must be a real root of the polynomial. Accordingly, by trying different values of X_0, an experimental graphical test for real roots of the polynomial can be carried out.

The method is of great fascination for high school students, and serves in a very loose way to show correspondence between geometry and algebra.

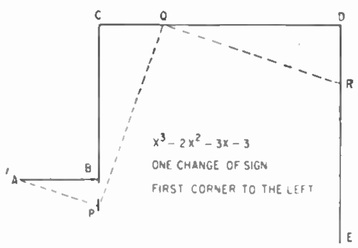

FIGURE 2

A look at the sides of the test trajectory indicates that the magnitudes are, in turn:

$$(1 + X_0^2)^{1/2} A_0, \quad (1 + X_0^2)^{1/2} \quad (A_1 + X_0 A_0),$$
$$(1 + X_0^2)^{1/2} \quad (A_2 + X_0) \quad (A_1 + X_0 A_0),$$

and so on, with the last being:

$$(1 + X_0^2)^{1/2} \quad (A_{n-1} + X_0(A_{n-2} + \ldots + X_0(A_1 + X_0 A_0).$$

Suppose we divide (or normalize) all of the sides by the factor $(1 + X_0^2)^{1/2}$, and consider the polynomial $P' = A_0 X^{n-1} + (A_1 + X_0A_0) X + +(A_{n-1} + X_0(A_{n-2} + X_0)$. Multiplying this by $(X - X_0)$ we get $y = A_0X_n + A_1 X^{n-1} + \ldots\ldots + A_n = P$.

Thus, the normalized components of the test trajectory represent the coefficients of the polynomial factor of P, after the root at X_0 has been removed. (The monomial $X - X_0$ has been factored out.)

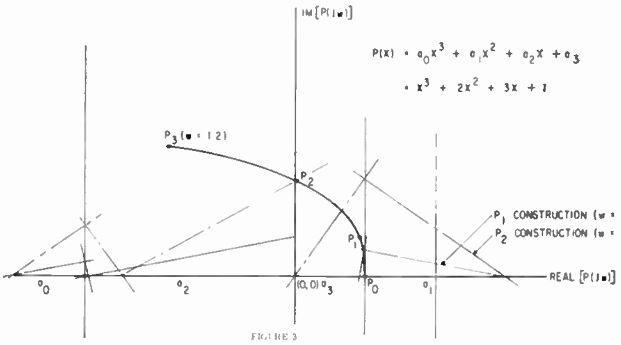

FIGURE 3

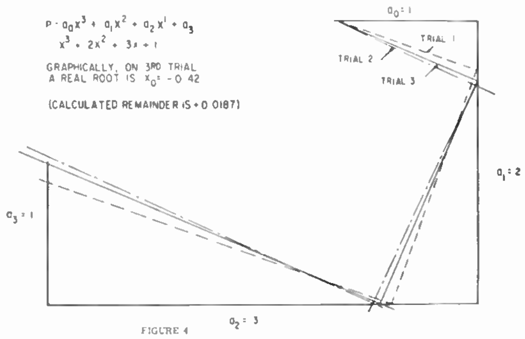

FIGURE 4

So, to find another root, one need merely try a test trajectory on a successful test trajectory, and the process can be combined so long as there are real roots, without any intermediate calculations. When there no longer appear to be any real roots left, the coefficients of this reduced polynomial can be scaled from the drawing and other techniques employed to locate complex roots.

The above property was demonstrated by L. E. Eisenberg in a somewhat more complicated manner in a recent letter in the G-AC Transactions[2], and he notes that there still does not appear to be any method for handling complex roots in such a graphical manner.

However, there is an interesting extension of the method applicable for plotting the complex loci of polynomials of pure imaginary variable. The Cauchy test for encirclements of the origin can then be applied graphically, all without specific numerical calculation—one of the objectives of this game. The extension is as follows. Separate the polynomial into even and odd parts, corresponding to real and imaginary parts P(iw). We assume that the coefficients were all originally positive. Then on the axis of reals, lay out, from the origin in consecutive sequence, the lengths A_n, A_{n-2}, A_{n-4}, to the right, identifying the beginning and the end of the segment. (If a coefficient is negative its direction is left.) Now we are in the position of having a real polynomial of a real variable consisting of only the even power terms, and we can take advantage of the remainder theorem noted above at the very beginning to evaluate this for particular values of $X = jw$.

This construction gives us the real part of P; similarly, for convenience, we lay out the odd coefficient on the negative real axis. For the same W we run down the power test trajectory concluding with the intercept on the vertical axis (axis of imaginaries). This is the imaginary part of P, and the values thus found, taken together, contribute a point on the locus for parameter (jw).

Figure 3 is a plot of $X^3 + 2X^2 + 3X + 1 = P(X)$ constructed in this fashion, for X = positive values of W only.

Before plotting, we check for solutions. Figure 4 shows that there is a real root at $X = 0.42$ and a test on the reduced polynomial (Trial 3) shows that it has no other real solutions. (A quick test on a quadratic polynomial is to join the start and end points with a straight line; then draw a circle with this as diameter. Where the circle intersects the A_1 line are the real roots of the quadratic. If there are none, the roots are complex.)

The plot of a polynomial must ultimately be closed by inspection, and approximately (that is, without linear scale preservation) because of paper size limitations. What is being plotted, of course, is a map of the complex X plane region consisting of the right half plane, and inspection of the number of enclosures of the origin by our plot indicates the number of roots in the right half plane.

As a matter of convention, the right half-plane lies to the right of the test contour as it is traversed in a clockwise direction, defining the "outside" of the system. If we have one root in the right half-plane our contour will display one encirclement of the origin, and so on.

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2. Eisenberg, L. E., "A Graphical Method for Finding the Real Roots of nth-Order Polynomials," IEEE Transactions G-AC, October 1967.

IEEE spectrum

Spectral lines

The International Convention. Some recent studies concerning the flow of technical information in industrial and governmental organizations indicate that engineers and scientists get most of their information from oral communication with other people. In an investigation[1] involving a survey of 2000 engineers and scientists, of which 1200 were IEEE members, it was concluded that electrical/electronics engineers in particular are dependent on other people for technical information and that less than 25 percent of the time they turn to the published technical literature to answer their questions. This is a sobering fact to the publications-oriented segment of the Institute. However, it does point to the importance of the conferences and meetings that the Institute sponsors. These can serve a vital role in the information-dissemination process.

The March International Convention of the IEEE has had a somewhat varied history as an effective mechanism for technical information transfer. Both through its technical programs and through its exhibits of production equipment and hardware, components, instruments, and systems, it provides a means for communicating and receiving technical information. In addition, it furnishes an opportunity for the informal interchange of information whose importance is hard to overestimate. If most technical information is transferred through interpersonal communication, it is certainly important to know the right people of whom to ask pertinent questions.

This year some particularly hard work went into the Technical Program. Under the imaginative chairmanship of Edward W. Herold of the RCA Laboratories, the Technical Program Committee has made a major effort to produce a Convention program that is more effective as a medium for information transfer. The philosophy used by the committee is discussed in the article entitled "The 1968 IEEE Convention Technical Program" on page 62 of this issue of SPECTRUM and will not be repeated here.

However, a publications-based analogy might be worth making. Most Group-sponsored meetings have an objective similar to that of the IEEE Transactions and Journals, that is, to make the specialist in a particular field a better specialist. These meetings and publications provide a communication channel for verbal or written messages from one specialist to another specialist, or, in many cases, would-be specialist.

In the Institute-wide publications, IEEE SPECTRUM and PROCEEDINGS OF THE IEEE, the objective is somewhat different. In SPECTRUM particularly, a conscious effort is made to furnish technical information to the nonspecialist at an appropriate technical level. There have been many indications that this objective of SPECTRUM is being met and is appreciated by members. In a somewhat analogous fashion, the 1968 Convention's technical program has been designed with a similar objective in mind. The criteria used for the selection of sessions, i.e., that the topics cross specialist boundaries and be of a tutorial or survey nature, would be suitable descriptions for many of the articles that appear in SPECTRUM. It seems very appropriate that the Convention program not be simply a combination of sessions designed for the specialist. This very necessary function is carried out with greater effectiveness by the Groups in the conferences and workshops they sponsor.

To pursue the analogy a bit further, the titles of many of the sessions sound like subjects for PROCEEDINGS' Special Issues. Indeed, several of these topics have already been used as subjects for Special Issues. In fact, the two sessions assigned to "Transportation" prove the point since the April issue of the PROCEEDINGS is also focused on this subject. It is interesting to note that the Technical Program Committee and the Editorial Board of the PROCEEDINGS independently concluded that this topic is one of great interest and significance not only to the public at large but to IEEE members in particular.

Among the other innovations this year is the inclusion of two tutorial seminars on "Integrated Circuits and Their Incorporation Into Equipment" and "Computer-Aided Circuit Design." These seminars, which require advance registration and a fee to cover the cost of the textual material received by the registrants, represent one of the initial efforts of the Institute to improve its continuing education services to members. More activities of this type should be expected in the future as the new Educational Activities Board, described in February 1968 "Spectral lines," gathers momentum.

The objective of the IEEE is to serve the membership and the profession as a means for making available technical information in ways that are most useful to its members. The 1968 Convention's Technical Program is an important step toward meeting this objective. It should point the way to continuing improvement in the Institute's efforts to fulfill its mission.

F. Karl Willenbrock

1. Rosenbloom, R. S., and Wolek, F. W., "*Technology, information, and organization*," Harvard University, Boston, Mass., June 1967.

Authors

Technical highlights of the 1968 IEEE Convention (page 62)

E. W. Herold (F) was born in New York City in 1907. He completed his undergraduate work at the University of Virginia, from which he received the B.S. degree in physics in 1930. He received the M.S. degree, also in physics, from the Polytechnic Institute of Brooklyn in 1942; the same institution awarded him the honorary D.Sc. degree in 1961. In 1924 he joined the staff of the Bell Telephone Laboratories, Inc., where he worked until 1926. From 1927 to 1930 he was employed by E. T. Cunningham, Inc. In 1930 he joined the Radio Corporation of America. He was associated with that company until 1959, by which time he had become the director of the Electronic Research Laboratory of RCA Laboratories' Princeton, N.J., facility. From 1959 through 1964 he was vice president in charge of research at Varian Associates, Palo Alto, Calif. From 1965 to the present he has been on the corporation research and engineering staff of RCA at Princeton.

Dr. Herold has specialized in electron tube and semiconductor device research for many years. He has participated in numerous IRE national and Section activities. He was a member of the IRE Board of Directors from 1956 to 1958 and a member of the Board of Directors of WESCON from 1963 to 1964. He is a member of Phi Beta Kappa and Sigma Xi, is the author of about 40 technical papers, and holds 44 issued U.S. patents.

Marcelino Eleccion (M) presently serves on the IEEE editorial staff as an assistant editor of IEEE SPECTRUM. Prior to receiving the bachelor's degree in mathematics from New York University in 1961, he joined the electrical engineering research staff at the College of Engineering of N.Y.U. in 1953, eventually attaining the position of chief electromechanical designer at the college's Engineering Research Division, which was headed by Dr. H. K. Work. After N.Y.U. formed the Laboratory for Electroscience Research in 1960, he was chosen to fill the newly created post of technical editor, responsible for the establishment and administration of both the editorial and the engineering drawing departments. In 1962, he was appointed the editor of publications, becoming responsible for coordinating Laboratory and Department of Electrical Engineering publishing activities involving research reports and proposals for Department of Defense agencies, doctoral dissertations, and technical papers for the professional societies. Mr. Eleccion joined the IEEE staff in October 1967. He has pursued his graduate studies at the Courant Institute of Mathematical Sciences, and is presently a member of the American Mathematical Society.

Planetary radar astronomy (page 70)

Irwin I. Shapiro received the A.B. degree in mathematics from Cornell University in 1950 and the A.M. and Ph.D. degrees in physics from Harvard University in 1951 and 1955 respectively. In 1967 he joined the faculty of the Massachusetts Institute of Technology as professor of geophysics and physics. Since 1954 he has been a staff member of the M.I.T. Lincoln Laboratory. He has devised many practicable experiments to test theoretical predictions, including two experiments to test general relativity theory by measuring gravitational effects on the propagation of electromagnetic energy. He has contributed to refining the exactness of planetary ephemerides, correlating optical observations with available radar data to determine more precisely planetary orbits, masses, radii, and rotations.

Sir Charles Wheatstone—forgotten genius (page 79)

B. R. Gossick (M) is a professor of electrical engineering and physics at the University of Kentucky, Lexington. He received the B.A. degree from Pomona College in 1939, the M.A. degree from Columbia University in 1941, and the Ph.D. degree in physics from Purdue University in 1954. In the period from 1942 to 1950 he worked as an electrical engineer for the University of Minnesota, RCA, and the NEPA Project at Oak Ridge, Tenn. Since 1950 he has been employed as a physicist at Purdue, Arizona State University, and Harpur College of the State University of New York. During the past 15 years he has done research on radiation effects in semiconductors, semiconductor barrier particle detectors, and the transient behavior of semiconductor rectifiers. Dr. Gossick is a Fellow of the American Physical Society and of the American Association for the Advancement of Science and a member of Phi Beta Kappa.

Utility system effects of space plasmas (page 93)

Russell L. Scott (M) is an application engineer on large synchronous and induction motors for use in electric utility power plant auxiliary drives. Prior to obtaining this position with the Electric Machinery Manufacturing Company, Minneapolis, Minn., he served as a field sales engineer with the Copperweld Steel Company, Glassport, Pa., where he was engaged directly in the study and use of communication facilities, transmission-line design, and the investigation of problems of conductor vibration and the rapid corrosion of underground-line hardware. His avocation of amateur radio is directed to the investigation of radio propagation and the effects of solar ionization and disturbances.

Mr. Scott was graduated from Carnegie-Mellon University in 1963 with the B.S. degree in electrical engineering. He is a member of CIGRE and is active in the Twin Cities Power Chapter of IEEE.

PROGRESS IN AN EXPLODING TECHNOLOGY

IEEE Convention 1968

MARCH 18-21

Technical highlights

This year's technical program represents a viable example of progress in an exploding technology and introduces a welcome "first" to the International Convention

E. W. Herold

Chairman, Technical Program Committee

Marcelino Eleccion

Assistant Editor

This article, along with the Convention Technical Program itself, is an innovation. It was written to explain the change in philosophy that underlies this year's meeting. The intent of the convention program planners was not just to add one more technical conference to the many already scheduled for 1968, but, instead, to provide something for the engineer's needs that is not available at those other meetings. In addition, there is included a description of the 49 technical sessions arranged in 12 groups.

This year, 1968, marks the first major change in the Convention Technical Program since its inception many years ago. Instead of an endeavor to solicit contributed papers covering recent specialized developments, we now have invited sessions, which cover only the most important and the broadest topics. A particular emphasis has been placed on filling the need of the average engineer to keep up with the art, and to learn about the new subjects, started outside the IEEE, which will be part of IEEE tomorrow. Our program should appeal to a Group member, helping to expand the scope of his Group's interest, and it should appeal to a non-Group member, who can adapt to the state of the art in current Groups. The sessions should attract the executive, or the man who plans to become one, and the marketing, sales, and production engineer, long overlooked in past Convention Programs.

The Program Committee organized the sessions carefully to meet one or more of three basic criteria: (1) the topics should be relatively new to the IEEE, (2) they should be interdisciplinary and extend beyond the interests of any one of our organized Groups, or (3) the subjects should be treated in tutorial or survey fashion, so as to be of value to someone who is not a specialist. Those IEEE Groups who helped to organize the third category of sessions were asked to have their papers aimed, not at members of their own Group, but at members of other Groups, or nonmembers of any Group. Based on careful planning around these criteria, the overall program is believed to be a balanced one, with something of interest for all. This selection leads to a program different from those available at other IEEE meetings.

To reduce parallel sessions, and to have larger meeting rooms, with better facilities, the total number of sessions has been reduced. In the regular portion of the program, there were 80 sessions in 1966 and 72 in 1967; this year there are 49. At the same time, many special features have been added, such as a display-demonstration-type Microwave Symposium at the Coliseum, two tutorial courses with textbooks and notes furnished, a workshop on presentation of papers, which includes an actor-presented play, and a Film Theater, with a special instructional feature of its own on large-scale integration.

There will be no published short abstracts of papers; in their place will be a Convention Digest, in which the authors of papers in the regular sessions present much more detailed reviews, complete with illustrations. To a man who cannot attend a particular session, the Digest is more valuable than our former abstracts, yet retains conciseness. For proper planning of his convention week, every engineer is urged to read this summary of program highlights, and also the session synopses, which are included in the detailed program beginning on page 13.

Special Highlight Symposium

One traditional feature of past Conventions has been the Tuesday evening Highlight Symposium. This year, the session has been organized as an integral part of the technical program, and serves as an introduction to four of the technical sessions that follow. The topic selected is one of the most important to the future of electronics;

of the 1968 IEEE Convention

namely, the solution of problems concerned with the world's resources, environment, and population.

Fortunately, much of the technology developed for space exploration is applicable, and Session Chairman R. C. Seamans, Jr., Deputy Administrator of NASA, is eminently qualified to define the theme of this meeting: "New Directions in Space." He will be followed by four speakers who will emphasize the United States' firm commitment to explore and exploit the infinite variety of earth resources by whatever oceanographic, geologic, or meteorologic means are necessary. The role of electronics as the key to this program will also be described.

Sessions 5E, 6E, 7E, and 8E on Wednesday and Thursday will explain how the electronics industry, *and* the engineer, will participate in this new commitment of science to human welfare.

Special sessions

Microwave presentations in Microwave Hall. The special microwave feature is novel in several respects. It is hardware or materials oriented, it includes displays and demonstrations, and every topic is repeated so that, if it is missed in one presentation, there is an opportunity to hear it in the other. Details are found in the session synopsis and program, organized by Dr. Leo Young, on page 16 of this issue. This symposium is a must for those who are active in the field.

Film Theater. Other meetings have effectively used selected films from industry, government, and other sources to present important and timely developments. This year, our program has done this and, in addition, is innovating in another respect. Included in the program and repeated each day is a specially made two-part recorded talk on the effects and status of large-scale integrated circuits; the speakers are outstanding leaders in this revolutionary field of solid-state technology, and the recording technique uses compressed speech with synchronized slides to cut listening time down to much less than the original. As with the films, this is a highly concentrated and effective way to absorb information, and should not be missed.

Tutorial courses. Requiring special registration in advance, the courses on Application of Integrated Circuits and Computer-Aided Circuit Design were scheduled so as not to interfere with any of the regular convention activities. They start each morning with a continental breakfast, and finish in time for attendance at the regular technical sessions.

Workshop—How to Present a Technical Talk. One of the most important skills that every engineer can use is that of organizing technical material for presentation to his management, to his colleagues, or to a technical society. This workshop consists of an original short play, in which the major effects of good and bad techniques are demonstrated in unforgettable fashion. It is followed by a panel discussion. Organized by James Lufkin, this special event will be invaluable to good speakers in improving their technique, and to bad speakers in showing them how they got that way. Scheduled so as not to interfere with the regular sessions or main convention events, it is repeated so that if missed on one of the days it can be heard on the other.

Regular technical sessions

Man and his machines. There are four interrelated sessions, 3A, 4A, 5A, and 6A, that concern the most important computer man has—his brain—and those many products that are designed by this computer—his machines. Session 3A (Tuesday morning) is called "Man–Machine Interface—Or Who's In Charge Here?" It becomes apparent that the machine can become so vital to the parent brain that the interrelationship of the two creates a new force, in which the question of who is in control becomes a key one. One of the papers in this session, by Gaines, is concerned with control of human learning, which is probably more influential in controlling the future than any other man–machine reaction we can envision—short of complete annihilation. Another paper (Senders) concerns attention and motivation, which surely affect the question of who's minding the store. Once, not so many years ago, man made pictures and graphics by himself, but today his machines do almost as well, as Noll shows in his paper describing computer graphics in acoustics research. By the way, Noll also authored an interesting paper in IEEE SPECTRUM[1] that closely relates to Session 5A, and in which practical computer graphics has actually led to esthetic creations.

In following up the "who's in charge" theme of Session 3A, Session 4A, "Man–Computer Communication" (Tuesday afternoon), explores the communication that exists between man's brain and its most intricate creation—the electronic computer. After two papers describe the results of large time-sharing systems and the computer-aided design of integrated circuits, another develops the possibility of using the computer as a mathematical assistant. A final paper introduces a method of obtaining a (machine)^n multiplication of intelligence that approaches the ultimate represented by the brain, that of interacting computer networks.

The man–machine concept is carried a step further in the four papers of Session 6A, "To Understand Brains. . ." (Wednesday afternoon), which endeavor to explain the brain in terms of a very complex, higher-order machine. Should this be carried out in detail, we would clearly be on the verge of designing the machine that will imitate, if not emulate, man himself.

The involvement of electronics, principally the computer, in the cultural interests of man has already been started in music, and is about to take place in art. In Session 5A, "Computer Output as Art" (Wednesday morning), two practitioners, Knowlton on computer "software" and Michaels on apparatus, discuss the uses of graphic computer output in the "science of the beautiful" as exemplified by pictorial art. Those who have read the previously described Noll article may come prepared to support the idea, or disparage it. In K. M. Bull, a Massachusetts art critic, they will have a spokesman who will speak for both sides. This session prepares us for that day when, after machines do all the work needed for physical survival, we might have to employ them for intellectual and cultural survival as well.

What we all need–education! The fast pace of electronics and electrical engineering has been so dazzling that few of us are convinced of our ability to stay even with, much less keep ahead of, the field. The same research that has caused this exponential increase in technology, however, can help reduce the hopelessness by stepping up the pace of the learning process itself. Many of the disciplines encompassed by the sessions of this convention owe their progress to the successful application of *computers* and *system analysis*. The same two techniques can be applied to education, and will be discussed in Session 1A, "Electronic Technology in Education," and Session 2A, "Engineering Education—Continuing Studies."

As the engineer becomes older, individual treatment of the learning process becomes essential for at least part of his continuing education. This individuality is expressed in three of the five papers of Session 1A (Monday morning). In essence, they emphasize individuality at all levels of learning, with close cooperation between society, the industry, and the educational system.

The remaining papers of these two sessions describe the growing reliance of teaching systems on sophisticated communication systems (television, "blackboard by wire") and high-speed digital computers. Every engineer and manager will find that these sessions are not to be missed.

...and some more that's new. After television, microwaves, and data processing, what are the next outstanding fields for electronics? The Technical Program Committee doesn't pretend to know the answer, but does claim that, whatever these new areas of interest for IEEE are, they're likely to be on the 1968 program!

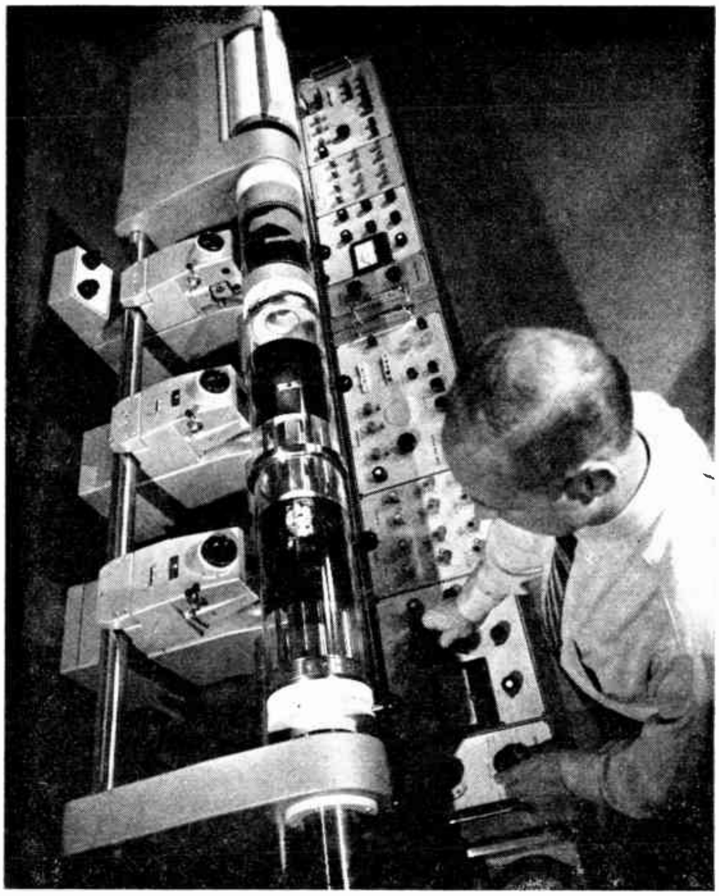
Some of these can be seen in Session 7A, "Marconi's Impact on Gutenberg" (Thursday morning), which covers almost every aspect of electronics in *publishing*—from the thoroughly new, such as composition, typesetting, and printing itself, to the somewhat more traditional subjects of control instrumentation, and distribution via facsimile or digital codes. The speakers are outstanding: J. J. Boyle represents the world's largest printer and publisher, the U.S. government; H. B. Archer is from the most famous graphic arts university in the U.S.; and H. F. George, E. W. Harslem, and J. S. Tewlow are from three of the most significant groups in the field. This session presents a rare opportunity to hear, from outside the IEEE, how important our industry has been and will become in the field of printing and publishing.

An area much talked about these days, but not officially recognized by the IEEE, is *psychophysics*. In a paper at Session 4C, "Psychophysics—A New Dimension in Engineering" (Tuesday afternoon), C. J. Hirsch shows that we wouldn't be where we are in radio and television if it hadn't been for Newton, Young, Helmholtz, Fechner, and other early investigators of sound and visual perception. Hirsch suggests that we've a long way yet to go in learning about man's perception of the electronic environment being built around him. Incidentally, in one of the most fascinating color demonstrations yet assembled, R. M. Evans proves the point by showing that there's much more to color perception than the ordinary expert in color television is aware of. A third paper is on A. C. Schroeder's theory of how one sees color, which is one of the more remarkable recent theories, applying waveguide concepts to the visual sensors of the eye. Regarding perception in general, binocular vision, which few of us really understand, is beginning to be susceptible to computer study by the use of the clever pattern generation that is described by Bela Julesz in the last paper of this session.

A feature of ultrasound that has hitherto been restricted to the laboratory, that of using high-power *ultrasonic energy* practically, will be introduced to IEEE members in the six papers of Session 4F, "High-Power Ultrasonics" (Tuesday afternoon). A product of the leading groups in this field, these papers will review applications, the powerful transducers necessary to make them practicable, and the techniques that aid their effectiveness. This extension of ultrasonics beyond such fundamental uses as cleaning will be shown to be of major industrial importance.

To the average IEEE member, *biomedical engineering* is old hat, yet except for EKG apparatus and the X-ray

MODERN electronic color scanner, as used in the printing industry (see Session 7A). The electronic controls for the analog computers provide a flexibility and precision not achievable with earlier methods.



machine, medicine is still practiced mainly with chemicals and surgery. Session 8A, "Planning for Payoffs in Biomedical Engineering" (Thursday afternoon), is devoted to showing that there is a predominating trend toward better understanding of the field, so that one can easily foresee electronics (and system analysis) playing a major role in bettering human health. However, it's important to bet on the right horse, not only on the track, but (metaphorically) in biomedicine as well. Session organizer O. H. Schmitt has four speakers who should be able to provide the "tip" for the IEEE man who doesn't want to miss this part of his future.

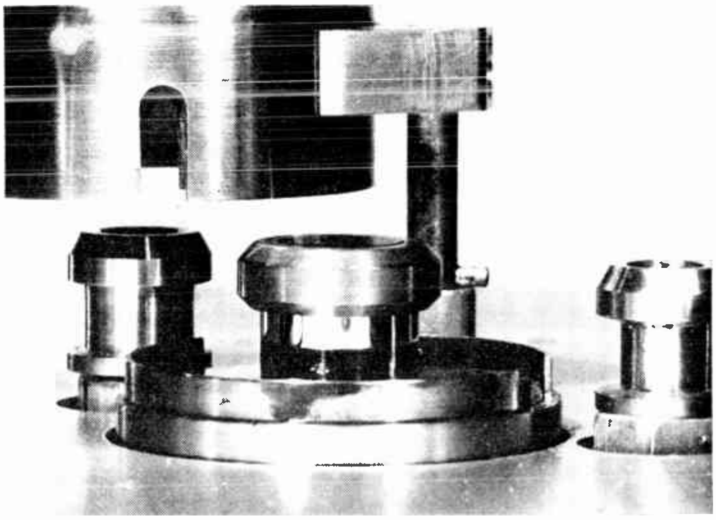
Measuring the payoff. There are very few sessions of the 1968 technical program that do not suggest to the enterprising engineer some way to advance himself economically, as well as technically. At the same time, most technical sessions are not directly concerned with economic values, or with the judgments that must be made as a result of their consideration. There are, however, five sessions that are so concerned; they cover management, invention, and the technological differences due to different economies throughout the world.

Session 1C, "Management of Research and Development" (Monday morning), features four papers on this subject, which concerns the fountainhead from which has flowed most of the economic rewards of our own industry. Session 2B, "The Patent Revolution" (Monday afternoon), discusses *patents*, which are the contracts between society and the inventor, and which have proved to be highly lucrative to both. One of the speakers, Arpad Bogsch, is a leading figure on the international patent scene, and speaks for the world community. The American view is sometimes considered more parochial, but the defending speaker, F. L. Neuhauser, will display the proverbial "other side" of the coin. This discussion ought to be extremely interesting to engineer and manager alike.

Session 3C, "New Technology and Engineering Economy" (Tuesday morning), is devoted to the technical aspects of engineering *economics*, that part of the engineer's training that has, alas, been so often overlooked: Each of the four papers covers a different facet of the subject, the total of which should provide the engineer with a better ability to measure "payoff" in terms of technical decisions. On the other hand, the four papers of Session 5C, "New Tools for Effective Management" (Wednesday morning), are concerned with better tools for these decisions, via the computer as an adjunct to the engineering manager, as well as to the engineer himself.

The last session in this "management" category is exceptional in that it brings together four top executives, each the head of a major company, from four different countries. The theme, of what will unquestionably be an exciting discussion, will be the technological differences between nations, their underlying causes, and their effects on our industry. The IEEE, as an international organization, must serve *all* of its members, and it is most important to recognize that technical and economic values in any one country may differ substantially from those elsewhere. A session such as 6C, "International Aspects of IEEE—Closing Technological Gaps" (Wednesday afternoon), may serve the 1968 Convention attendee to develop better understanding of his IEEE associates who live under such different value systems.

The earth and the space around it. In spite of the advances in science and the refinements of civilization,



MARK II information rate changer rotating head assembly showing mu metal shield; azimuth adjustment guide is on the left and wrap angle adjustment guide is on the right. (See Film Theater.)

man's survival is dependent upon the proper adaptation to, and effective use of, his worldly environment. Four sessions, 5E, 6E, 7E, and 8E, are the follow-up to the Special Highlight Evening Symposium. They are concerned with obtaining data for both exploring and exploiting the many resources of this environment and for weather prediction, and with the communication systems required to obtain such data, including ordinary point-to-point communication.

The interesting fact emerges that the total view of land and ocean from space, using all the parts of the spectrum for which sensors are available, adds a new dimension to our ability to analyze, predict, and utilize this environment. Nevertheless, space data alone, using radio, light, and infrared radiation from the earth's surface, constitute only one tool. Suboceanic and subterranean telemetering systems also play an important part. One of the papers in this group of sessions discusses image processing by way of holographic techniques, whereby *any* pictorial data can be enhanced in value. (This specialized paper is a fitting one to follow the more general treatments of optical processing and holography found in Session 4D.)

Sessions 5E, "Earth and Environmental Sciences—Exploration" (Wednesday morning), 6E, "Earth and Environmental Sciences—Exploitation" (Wednesday afternoon), and 8E, "Potential Observing Techniques for the World Weather Program" (Thursday afternoon), have sufficiently descriptive titles not to require comment. Session 7E, "A Survey of Satellite Communications" (Thursday morning), is exclusively devoted to satellite communication links from one point of the earth to another. It is hoped that all of these topics, when they are better understood by the engineer, will provide the key to controlling man's resources and environment. This, in turn, should enable mankind to adjust to its problems of overpopulation, underdevelopment (in some parts of the world), and overdevelopment (in other parts).

Building blocks for systems. A measure of an engineer's success is contained in the systems that result from his work. Reliability, accuracy, and performance of a system, however, largely depend upon the constituent subsystems. These integral building blocks are the subject of six sessions, all concerned with the materials, components, devices, techniques, and packaging disciplines that are so important to our systems of the future.

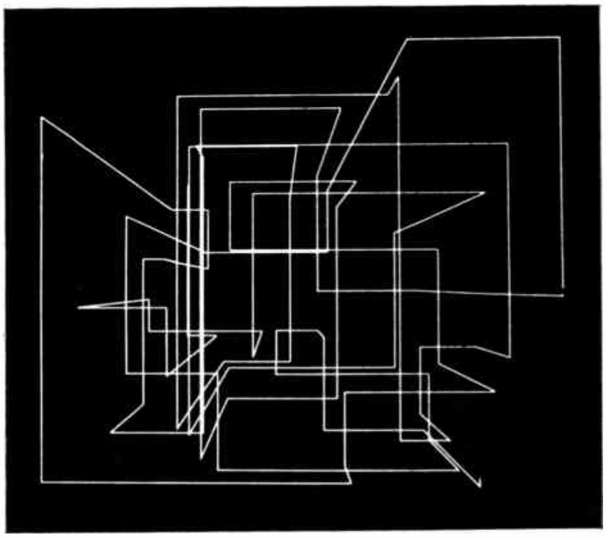
Solid-state materials and phenomena are at the core of system and device performance and Session 2D, "What Can Technology Expect from the Solid State?" (Monday afternoon), serves as an introduction to some of the other sessions. Four experts look into the present state of the art of magnetic, piezo- and ferroelectric, superconductor, and semiconductor materials and phenomena—extrapolating today's knowledge into device considerations of the future. Although the semiconductor remains a material with the greatest short-term impact, few engineers can remain unaffected by the combined technologies of these four areas.

The application, safety, and evaluation of subsystem components are the concern of three sessions. There are four papers in Session 3D, "Large-Scale-Integration Technology and Its Application to Computer Systems" (Tuesday morning); the first two concern the *extent* of LSI customizing that will be required, and the second two establish a *rationale* for the installation of LSI into large and small computers. Session 5F, "Fuse Considerations for High-Power Semiconductor Applications" (Wednesday morning), contains six papers that instruct the engineer on how to protect very-high-power semiconductor devices against unintended surges and overloads.

Once a subsystem component is inserted into the overall system and becomes a member of a semiconductor array, the detection of deviant behavior becomes an enormous chore. Fortunately, test equipment has been developed from infrared technology which not only has been able to evaluate components prior to encapsulation, but can "fingerprint" entire microelectronic systems while in full operation. Among the four papers and three films of Session 4B, "Infrared Radiometry" (Tuesday afternoon), the paper on NASA's fast-scan infrared microscope, and the film on the COMPARE infrared test system for solid-state circuits describe two systems that exhibit a testing versatility of uncommon proportions. These testing systems can be said to add a "sixth sense" to conventional information systems.

The proper assemblage of components into appropriate modules and packages is a necessary step in "fitting" the building blocks to a system. The evolution of monolithic circuits into medium- and large-scale integration systems has further complicated the problems first created by printed circuits. The four papers contributing to Session 7D, "Systems, Materials, and Packaging Disciplines" (Thursday morning), provide answers to the more urgent problems facing intra- and interconnection techniques by offering "software" in addition to "hardware" approaches. Specific coverage is given to interconnections in hybrid systems, unique packaging characteristics for spacecraft, minimizing connections of microelectronic components to facilitate repair and replacement, and the use of substrates to reduce interconnection problems.

As an introduction to an important building block of future electron devices, Session 4D, "Applications of Coherent Light Technology" (Tuesday afternoon), will feature five papers on the laser and its applications. In addition to a paper covering the all-important aspect of holography, and another defining data-processing tech-



EXAMPLE of computer-generated art, courtesy of A. M. Noll (see Session 5A).

niques using optical images, the nonlinear effects that have been so useful in building radio- and microwave-frequency devices in the past will be adapted to optical frequencies by Geusic of BTL. This technique holds unlimited potential for future nonlinear and parametric devices. A survey of lasers for displays, and a review of the status of the revolutionary laser gyro, will round out this very complete session on laser technology.

Systems and how to build them. The byword in electronics today is the "system." Everywhere we go, in the military and in industry, we hear of the "system approach." Whenever electronic experience is called upon to advise in education or in politics, or to propose a cure for social evils, one inevitably hears these same words. In looking over the 1968 technical program, therefore, it should come as no surprise that systems-related topics comprise the largest single assemblage. The IEEE member who has not yet adjusted himself to this technique for the future would do well to take heed!

The design of systems has come a long way in the past two decades. In Session 8C, "A Debate on Techniques for System Synthesis" (Thursday afternoon), various protagonists will compare the results of three different methods of system *synthesis*: namely, digital simulation, use of design indexes, and use of Bayesian statistics. The session organizer promises a lively debate among the speakers, and will try to play an objective part himself as moderator. Session 5B, "Digital Simulation—Key to System Design" (Wednesday morning), is closely related; the speakers here appear to have already made up their minds, since all five use digital simulation as their technique. Specifically, this computer-oriented approach (what isn't these days?) is used to design communication, computer, and power systems in a powerful argument for this method.

A system that breaks down suddenly moves from the "asset" column to the "liability" column; hence, system *reliability* and *maintenance* are critical factors for success. There are four sessions in the program that allow for close examination of both the present status and future trends in this vital area. The four papers of Session 5G, "Assessment of Reliability Techniques" (Wednesday morning), carefully examine the reliability of military and commercial systems, and the criteria required for microelectronic and component reliability. In the afternoon, there is a practical discussion of maintenance in the field (Session 6B, "Broadening Scope of Field Support and Maintenance"), and specific examples of a large seismic array system, a test range, and an early-warning system serve to provide the audience with the background necessary to design and evaluate maintenance problems of other kinds.

The two companion sessions, 7B, "Automated Maintenance—Theoretical Aspects" (Thursday morning), and 8B, "Automated Maintenance—Field Experience" (Thursday afternoon), carry the idea of maintenance a step further by presenting the theoretical and practical aspects of *automatic* fault detection, location, and repair. This is an exciting prospect for keeping a system in the "asset" column, and three papers of 7B permit more effective design by discussing the methods of automatic fault simulation and the automated maintenance of computers. A fourth paper covers similar considerations for the nondigital (i.e., linear or analog) type of system. Fortunately, some of these theoretical ideas can be backed up by the experience of one of the oldest electric systems we have—the telephone. Thus, the three European and two American companies that discuss the automated detection and diagnosis of system faults in Session 8B represent a first step toward complete automation.

If one of us were asked to design a system for the planet Venus, would automatic maintenance and repair be enough? Clearly it would not, which leads us to the natural extension of such systems—the *adaptive* or self-learning system. Our own body is, of course, a beautiful example of this, for it contains homeostatic as well as dynamic adaptive features. Session 7C, "Adaptation and Learning in Systems" (Thursday morning), includes five papers on this topic, from theoretical concepts about adaptive curve fitting, to practical application of an adaptive antenna system. One of these papers is written by a leader in this area from the U.S.S.R., and his paper on adaptation and learning in automatic systems is expected to reveal recent advances in that country.

There is another problem in systems design and practice, which is very basic but as yet not fully determinable. This is the subject of Session 6G, "Integration vs. Confederation: Which Criteria for Aerospace Systems?" (Wednesday afternoon). For an aerospace system, just how far *should* one go in integrating a unique system? Three highly placed and highly qualified speakers from the armed services, and two from industry, describe how the problem has arisen, and the pros and cons of integration versus confederation. The former notion implies an almost complete interdependence of all the components and subsystems; whereas confederation, just as on the political scene, permits substantial independence among the system parts. A panel discussion following the formal presentation of papers should add contingent and unscheduled color to an already fascinating session.

Sources of energy. Energy is one topic about which no one is satisfied. If we don't have enough energy, we cannot develop our other resources, and even when there is plenty, we worry about pollution and depletion. The world's transportation network, most of which relies on fossil-burning energy systems, is possibly a major danger (recent queries by scientists seriously challenge the continuance of nature's delicate CO_2-oxygen balance), and produces high noise levels and inevitable fuel depletion. Air pollution is now as important as economy in the future construction of generating plants for electric energy; and the exotic power requirements of space demand maximum efficiency and operating time combined with minimum size and weight.

Some of these requisites have been met with more than partial success by the development of nuclear reactor plants[2,3] and fuel cells. The three papers of Session 3E, "Energy Sources" (Tuesday morning), are particularly designed to present topical coverage of these energy sources—from basic principles to current state of the art. Fuel cells, electric automobiles, and nuclear energy conversion are provided ample coverage by representatives of NASA, GM, and the AEC.

In keeping with the interdisciplinary nature of modern science, Session 5D, "Better Electrical Products from Chemistry" (Wednesday morning), will demonstrate how electric devices, particularly batteries and fuel cells, have benefited from the allied fields of chemistry. The materials and techniques that have enabled electrical insulation, solid-state devices, batteries, and fuel-cell processes to progress are the topics of four of these papers; the fifth presents a review of the chemistry and technology of the power sources of today and tomorrow.

Better ways to get from here to there. Recent articles by G. D. Friedlander[4] and E. L. Michaels[5] in IEEE SPECTRUM, and perhaps one's own demonstrable frustrations, have called attention to a burgeoning problem that has reached epic proportions—the restrictions on safe and quick travel that are imposed by the close concentration of an overabundant populace.

It is not surprising that computers and automatic control techniques play an important role in the solutions offered by Sessions 1E, "Transportation—I" (Monday morning), and 2E, "Transportation—II" (Monday afternoon), since speed and reliability are the essence of any solution to this problem. Although particularized to the Northeast Corridor, the M.I.T. study in Session 1E develops the problem of high-speed ground transportation and can serve as a general introduction to the other papers. One of these describes a novel taxi-bus system called "Genie"; and the remaining two discuss trends in rail transportation, and introduce error-ratio measurements of a computerized teletypewriter system that might well influence the railway's fight for survival.

Session 2E is primarily concerned with the automobile; two papers emphasize the problems of highway automation, and two describe modern developments in intersection control, including Toronto's highly successful traffic control signal system.

Uses and abuses of the ether. Many IEEE members make their living out of the use of the ether. To someone concerned with a radiation-susceptible system unrelated to communication, there is always the question of whether one fellow's "use" isn't someone else's "abuse." Session 1F, "Effects of Electromagnetic Energy Outside of Communication" (Monday morning), deals with this problem well beyond the conventional interference and noise. The effects on biological systems, on our environment, and on nonradio equipment have not usually been known to the persons responsible for the source of radiation. The three papers in 1F are designed to dispel this ignorance and show the truth of the old maxim, "it's an ill

COMPARE system (see Session 4B) achieves automated troubleshooting analysis of the infrared signatures of electronic assemblies.

wind . . ." In the paper by Buehler, for example, there is evidence that radio noise, a form of air pollution, can be turned to advantage to predict temperature inversions and smog.

Another form of ether abuse comes from overcrowding, and Session 2F "Propagation in New Spectral Regions" (Monday afternoon), is an important survey of the characteristics of microwave and millimeter wavelengths, as affected by the atmosphere and the weather. Expansion in this region appears to be essential and a knowledge of the problems to be faced will help many an engineer adapt to the future.

The five papers of Session 3F, "Recent Advances in Radio Wave Propagation" (Tuesday morning), deal with conventional frequencies, between HF and SHF, but they disclose unconventional knowledge about their use under special conditions. Among the topics covered are jungle radio propagation and long-range communication with deeply buried antennas, all at lower frequencies; short-wave (HF/VHF) propagation using the earth-detached, wide-band, low-loss ionospheric "whispering gallery"; predictions of coverage and interference by low-antenna measurements over irregular terrain at VHF/UHF; and a survey of what is known and unknown about terrestrial interference with satellite communications links.

1968's best engineering tool—the computer. Man-machine interaction was the topic of a previous group of sessions. The present group, however, explores the theme of "problem solving." The question here is no longer "who is in charge?" but "what must be done?" To this end, any technique that can increase accuracy and reliability while shortening real-time operation is acceptable. Throughout these sessions, the computer has proved itself an invaluable aid to the investigator. In short: the problem's the rub—and the computer's the "solve"!

The increasingly complicated types of information processing introduced by computer technology require unique solutions, and the five papers of Session 1D, "New Ideas in Information Processing" (Monday morning), run the gamut. High-speed requirements for large-scale integration and computer-graphic addition and multiplication are solved by integrated circuitry and hybrid analog–digital methods in the papers by Chung and Hagen. Representation of variables is enormously simplified by Gaine's use of random pulse sequences; and two new methods of information transfer by fiber optics are outlined by a trio from the American Optical Company. Finally, a means of storing and retrieving this information by holography is introduced by Kalman.

The complexity of most problems require that the engineer's approach—especially in the face of time-sharing and cost considerations—be founded on already well-established techniques. The specific applications contained in the two papers of Session 2C, "Computer-Aided Engineering" (Monday afternoon), describe small-card wiring changes and an on-line flight data conditioning system. It is likely that these two techniques can be extended to embrace problems of a more general nature, in turn extending the value of these papers to the listener. Two other papers cover rapid synchronous logic simulators and the COMMEND I program, designed to play an increasing role in faster and better mechanical design.

Optimum computer performance can be additionally improved by the adroit selection of methods similar to those described in Session 4E, "Modern Algorithmic Methods for Computer Solution of Electrical Engineering Problems" (Tuesday afternoon). The common pitfalls confronting the novice are tutorially outlined in the two papers covering the discriminate use of preconstructed subroutines and numerical analysis programs. Specific treatment of complex waveforms through filters is given by Hamming, and an iterative method for the fast Fourier transform is described by one of its innovators, Cooley of IBM.

The three sessions in this grouping should greatly help those with a little sophistication in computer technology to improve their skill, and those who have no background to appreciate what they are missing.

. . .**and we should also mention these.** The 1968 Conference should make the engineer aware of the diversity of research "tools" that are at his disposal. In addition to the computer, which has become synonymous with speed and efficiency, a practically bottomless "tool chest" stands within the grasp of every scientist to help him develop his understanding and stimulate his imagination. One such tool is *information theory*. Formerly discounted as a "curious intellectual game," Shannon's brainchild has given substance to digital computers, extended the scope of deep-space communication, simplified automatic control, clarified language processing and pattern recognition, and contributed fundamental concepts to the behavioral, management, and biological sciences.

Session 6F, "Progress and Trends in Information Theory" (Wednesday afternoon), is a state-of-the-art survery of this field. There are two papers that describe the threefold increase in the data-decoding rate of space telemetry and the practical decoding algorithms that are offered by information theory. A useful approach to pattern recognition, and the limitations of data-compression techniques are the topics for two more papers. Still another paper includes a history of how theoretical results often show up mistakes in engineering intuition (examples are given from radar, radio astronomy, communications, and seismic instrumentation), and instructs the practicing engineer on how the current theory can be applied to his own problem.

The rapid developments in large-scale integration of digital circuits previously described have made the application of *digital-filtering* techniques feasible in a shorter time than expected. This is the topic of the four papers in Session 7F, "Digital Filtering—The Promise of LSI Applied to Signal Processing" (Thursday morning). A panel discussion on the implication of digital filters should complete the understanding of a method that threatens to end the virtual monopoly of its analog counterpart.

The successful application of relatively simple digital methods to intricate systems is indicative of the temper of present-day science. The system interference attributed to existing wireless transmission methods would certainly be curtailed if a number of them could be transmitted over the same channel. Even more practical, wire systems could operate at higher efficiencies with fewer lines. All this is made possible with *digital communication* systems, and the four papers of Session 8F, "Transmission Bit by Bit" (Thursday afternoon), treat the basic problems in turn—processing, switching, multiplexing, and transmission. It is essential that every well-rounded engineer learn the fundamentals of this versatile tool, bit by bit!

Electronic ingenuity has accounted for one of the most invaluable research instruments of the 20th century—the *particle accelerator*. This tool has established nuclear physics as one of the leading modern sciences, and the authors of the five papers in Session 1B, "Recent Advances in Particle Accelerator Technology" (Monday morning), will attempt to explain why. One paper describes a recently completed 20-billion-volt accelerator, and a second reveals the plans for the world's largest, about which we have heard so much: the machine to be built in Illinois. Another paper outlines the coming generation of highly flexible medium-energy accelerators; and a fourth measures the impact of computers on the control of these devices. As an added attraction—as though one were needed—a paper on the potential use of superconductive properties in accelerator design will show just how revolutionary these tools can really be.

The immediate detection of voltage differences that may make or break a system sometimes demands *voltage measurement* devices with an accuracy of several parts in a million. With this in mind, Session 3B, "The Op Art of Voltage Measurement" (Tuesday morning), includes a paper describing the new generation of digital voltmeters, and one that describes the total acceptance of the Zener diode as the working dc voltage standard for most precise electric instruments. This session, tutorial in nature, also reports on the characteristics and performance of active dc voltage standards, in addition to developing the design criteria for the generation of precise ac potentials in and beyond the audio-frequency range.

The publicity accorded early superspy disclosures and more recent cinema spoofs has created close public interest in the electronic *surveillance* techniques employed by these "masters of deceit." If this influence were restricted only to television serials, magazine ads, and children's toys, perhaps no more would come of it. However, the four papers of Session 6D, "Electronics and Privacy" (Wednesday afternoon), call serious attention to the various individual, national, and legal aspects of this ubiquitous invasion of privacy that can result from the overzealous use of a most powerful electronic tool.

In this session, a paper by B. Jamil reveals the state of the art of surveillance equipment, to establish a framework for the other three papers. The actual distinction between the passive and active use of electronic devices either to provide security or to destroy privacy is defined by J. D. Foster in his treatment of the subject. Whether the electronics engineer should remain in silent acquiescence or insure that adequate safeguards are provided in the information-processing systems of the future is a highly ethical question, however. The extent of ethical responsibility in designing these privacy safeguards is the theme of P. Baran's paper on the threat of future data centers. Although opinions seem divided over this issue, it remains to be seen what the engineer makes of his unique and highly personal position.

Which brings us to the much-touted legal aspects of surveillance that will be presented by a distinguished guest speaker, A. Yarmolinsky of the Harvard Law School. Although electronic surveillance may at times be necessary in terms of local and national security, much of it is done on the personal and corporate level. All of it, however, concerns the delicate question of constitutional rights, and recent test cases involving local and federal sleuthing practices have defined the limits within which these agencies must operate. Future court decisions are expected to extend these definitions even further.

Epilogue

The Technical Program Committee has tried hard to meet program objectives that are, indeed, different and that provide help to every Convention attendee. Success will be evaluated by the response of the readers of this article, both in their attendance at the technical sessions and by their opinions (which IEEE members have seldom been backward about expressing). If the objectives are met, and the program helps our members move ahead in the technical explosion evolving around us, the Institute will owe a great debt to the many hard-working session organizers, and the speakers they have invited, whose participation is the heart of any technical program. We look forward to seeing you at the Convention and we welcome your comments.

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Planetary radar astronomy

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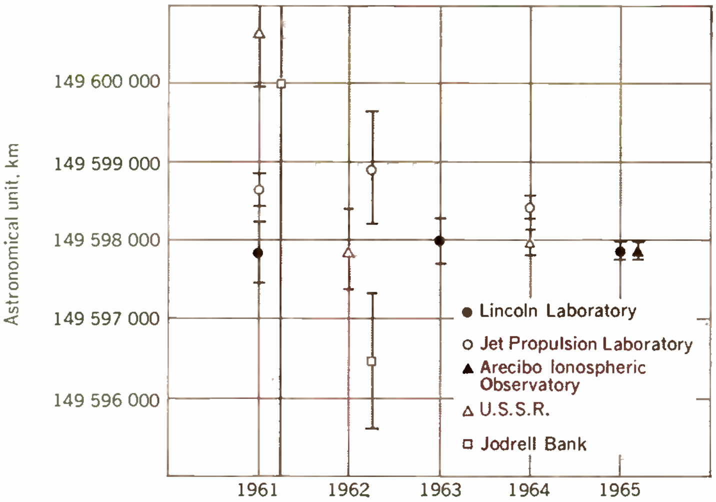
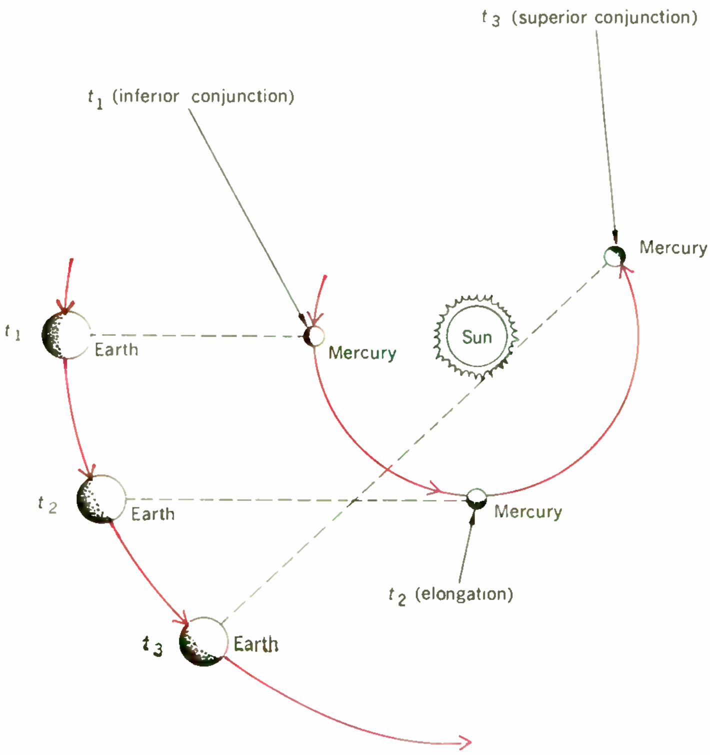


FIGURE 1. Radar determinations of the AU through 1965. (Velocity of light assumed to be 299 792.5 km/s.) The most recent Lincoln Laboratory and Arecibo determination is consistent with the 1965 value but several orders of magnitude more precise.

FIGURE 2. Geometric illustration of the increase near superior conjunction of sun's predicted effects on interplanetary time-delay measurements.



Measurements of the time delays and Doppler shifts of radar waves have been used to determine the orbits, radii, and rotation vectors of the inner planets and to improve by almost five orders of magnitude the accuracy of relating the Astronomical Unit to a terrestrial unit of length.

A decade ago, planetary radar astronomy was merely a glint in the eyes of a few electrical engineers and physicists. After a rather long gestation period—some six times the normal human complement and marked by several bouts of false labor[1,2]—bona fide radar echoes were detected from Venus during the inferior conjunction of 1961. Significant data were obtained at that time by groups at the Lincoln Laboratory,[3,4] the Jet Propulsion Laboratory (JPL),[5] Jodrell Bank,[6] and in the U.S.S.R.[7] Since then radar contacts with Mercury and Mars have been made in the U.S.S.R.[8,9] and at JPL,[10,11] the Arecibo Ionospheric Observatory,[12,13] and the Lincoln Laboratory.[14] Although in 1963 some claimed to have detected echoes from Jupiter,[15,16] these were quite weak and have not been verified by later experiments.[17] Nevertheless, it is fair to say that radar results from the past five years have in scientific importance already far exceeded the most optimistic predictions. I also suspect that the useful scientific lifetime of planetary radar observations is far from expended.

What types of information are obtainable from radar observations of the planets? Although categorizations are always somewhat arbitrary, it is convenient to speak of the following three types:

1. Planetary motions (both orbital and spin).
2. Planetary surface characteristics (features, roughness, albedo, dielectric constant, and topography, although some are not easily determined unambiguously.
3. Properties of the intervening medium (planetary atmospheres and ionospheres, interplanetary plasma, and solar corona).

It is not possible to explore all of these subjects here, even cursorily. I will therefore concentrate on a few experimental and related theoretical results already obtained, and on some interesting experiments that, hopefully, will be performed in the reasonably near future.

Interplanetary radar measurements have uncovered the startling resonance rotations of Mercury and Venus and have made possible a new test of general relativity

Planetary orbits

The extension of radar measurements to interplanetary distances heralded a major advance in the study of planetary orbits. One might at first wonder of what use a few years of radar data might be, considering the existence of centuries of precise optical observations of the planets. The importance of the radar data for such studies derives from two facts: (1) Radar adds two dimensions to the space of measurements, namely, the time delay and the Doppler shift of the radar signal reflected by the planet. (2) The radar measurements are of unprecedented accuracy, precisions of one part in 10^8 having already been achieved in time-delay observations. But in any event, why should anyone want to add the $n + 1$st significant digit to the expressions for the planetary orbital elements? First of all, there is the practical matter of the exploration of the solar system. In planning such missions, knowledge of the distance to the objective is vital. Astronomers express all interplanetary distances in terms of the astronomical unit (AU), but prior to the radar measurements the relation between the AU and the kilometer was only poorly known—to no better than one part in 10^3. Considering that no planet approaches closer to the earth than 4×10^7 km, one readily discerns the seriousness of 0.1 percent errors. The first successful measurements of interplanetary time delays reduced this uncertainty by two orders of magnitude to one part in 10^5 and contributed significantly to the success of the Mariner II mission to Venus.

In Fig. 1 are shown most of the past radar determinations of the AU in terms of kilometers.[17] Note that the Lincoln Laboratory value has remained constant as the accuracy improved and that the U.S.S.R. value is now in close agreement with it. The Arecibo data, processed at Lincoln Laboratory, also yield essentially the same value.

From a strictly theoretical viewpoint, the more accurately one knows the planetary orbits, the more decisive will be the test of the related physical laws, which in this case are embodied in Einstein's theory of general relativity. This magnificent intellectual creation is unique among physical theories in having achieved almost universal acceptance with little experimental verification. Aside from the red-shift experiment,[18] which many physicists do not consider relevant to testing the detailed structure of the theory, there have been only two tests of general relativity, although many others have been proposed. The bending of starlight passing near the limb of the sun has not given satisfactory quantitative results despite attempts during almost every total solar eclipse since 1919. The predicted deflection is at most 1.75 seconds of arc, and is quite difficult to measure photographically, since plates exposed during conditions of total eclipse must be compared with those taken six months later (or earlier) at night under quite different conditions.

The other test, involving the observed anomalous 43 seconds of arc per century advance in the perihelion of Mercury's orbit, seems to agree with the theoretical predictions of general relativity to within 1 percent. On closer inspection this test, too, appears somewhat unsatisfactory. For example, one could not now distinguish from its other effects a solar quadrupole moment of magnitude sufficient to account for about 20 percent of this anomalous advance.[19]

Improvements in radar system sensitivity have made another test of general relativity technically feasible.[20] According to general relativity, in addition to being bent, a light signal (or radar wave) will slow down near the sun. This prediction is just the opposite of what one might naively have expected. Although matter speeds up, light signals slow down upon approaching a massive body. In both cases, however, the trajectory bends toward the attracting center. How can this effect be measured by radar? Suppose we follow an inner planet around its orbit with radar signals. Only in the vicinity of superior conjunction will the signals pass close to the sun, as illustrated in Fig. 2. In fact, between inferior conjunction and elongation, the radar signals never penetrate the orbit of the target planet and hence are substantially unaffected by the solar gravity. The quantitative contributions to the delay predicted to result from solar gravity are shown in Fig. 3. The small, almost constant value of this extra delay between inferior conjunction and elongation can be shown not to be operationally significant.[21] The maximum effect, of course, occurs when the signal grazes the sun and is about 200 μs.*

*The Doppler shift corresponding to the time rate of change of this extra delay appears to be too small to be measured accurately at present.[22]

What hidden difficulties could prevent this extra delay from being detected? In the first place, one does not know precisely what delay to expect in the absence of a general relativistic effect, since neither the position of Mercury nor the position of the radar site is known exactly. Of course it is true, as intimated earlier, that the optical observations have led to orbital element determinations accurate to n significant figures. The difficulty is that n is not large enough! Even if it were, we should still be faced with another problem. The orbits are conventionally described in coordinate values determined from Newtonian theory. What are the corresponding coordinate values in general relativity? The answer is simply that this is the wrong question to ask. The coordinates per se have no operational significance. One has to take the measurements themselves and reduce them consistently within one theoretical framework to estimate the unspecified values of the parameters in the theory such as the orbital initial conditions, the masses and radii of the planets, etc. With radar time-delay measurements made at a large number of points around both orbits, the parameters can be estimated accurately enough so that the orbital "positions" will be known to within 1.5 km (5 μs). Near superior conjunction, the predicted relativistic effect should therefore be measurable with an error no greater than 10 percent; the percentage accuracy will of course be less nearer elongation.

In this analysis, I have been tacitly assuming that the radar signal is unaffected by the medium between the earth and the target planet. The most important effect is caused by the plasma in the solar corona, which also tends to slow the propagation speed of the signals. Fortunately, this plasma effect is inversely proportional to the square of the radar frequency. General relativity, on the other hand, predicts no dispersion. If one conducts a two-frequency experiment, the plasma effect can be estimated and subtracted. Alternatively, if a sufficiently high radar frequency is employed, the effect of the corona can be reduced to an insignificant level. Another coronal problem will be turbulence, which will disturb the coherence of the radar signals and consequently reduce the signal-to-noise ratio and the achievable measurement accuracies.

Although no high-frequency radar observations have yet been attempted near the superior conjunction of either Mercury or Venus, many measurements of time delays and Doppler shifts between the earth and each of these planets have been accumulated and may be used to refine some of the solar system constants. Recently, data from Arecibo and Lincoln Laboratory have been combined in a large digital computer program to obtain simultaneously best-fit values for the orbital elements of the observed and observing planets as well as for the AU, the earth-to-moon mass ratio, and the radii and masses of the two inner planets.[23] The AU was found to be 499.004 786 ± 0.000 005 light seconds, which corresponds to an estimated error of only four parts in 10^8. The accuracy in determining the kilometer equivalent of the AU is limited by the imprecision in the determination of the speed of light in kilometers per second—about one part in 10^6.

The interplanetary time-delay measurements are sensitive to the earth-to-moon mass ratio because of the motion of the earth about the center of mass of the earth–moon system. The value of 81.303 ± 0.005 found from

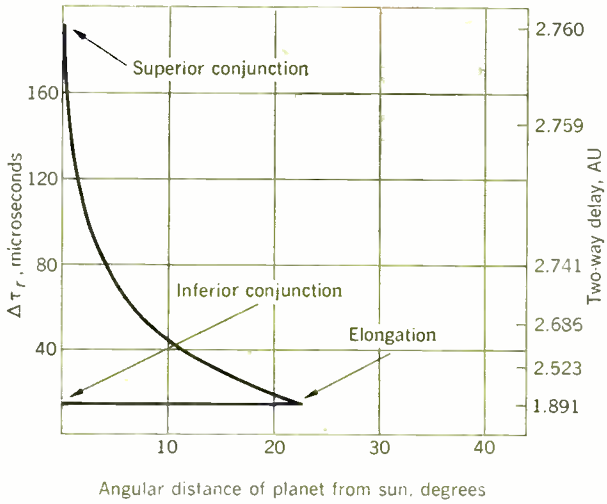


FIGURE 3. Contribution of general relativity to earth–Mercury time delays in the limit of circular orbits.

the radar observations is in very good agreement with the 81.30 value adopted at the XIIth General Assembly of the International Astronomical Union. The radii of Mercury and Venus were found to differ from the conventionally accepted values[24] by about 15 and 45 km, respectively. The errors in the radar values of the radii are estimated to be only a few kilometers—an order of magnitude smaller than the errors obtained in prior determinations.

In terms of inverse solar masses, the value for the mass of Mercury was found to be 6 020 000 ± 50 000 (in decent agreement with the most recent determination of 6 110 000 ± 40 000 obtained from optical data[25]). The estimated mass of Venus also agrees with the conventionally adopted value but, being determined to only one part in 10^3, does not have nearly the accuracy of the latter.

Orbital elements to which the radar measurements are most sensitive appear to require corrections in about the sixth significant figure, except for the orbital periods, which are known to a far greater accuracy. As an indication of the decrease in the residuals resulting from the reduction of the radar data, compare Figs. 4 and 5. The former shows the difference between the earth–Venus time-delay observations and the corresponding theoretical predictions based on JPL's numerical integrations of the equations of motion that were matched to Newcomb's orbits. Figure 5 gives a similar comparison with the JPL ephemerides replaced by ones determined by the simultaneous least-mean-square fit to the earth–Venus and earth–Mercury time-delay and Doppler-shift observations. The corresponding residuals for the earth–Mercury observations exhibit comparable decreases.

In the future, one can expect radar observations to lead to significant improvements in these and other solar system constants. When the satellites of Jupiter, Mars, and Saturn become observable with radar, as they might within a decade, estimates of their orbits, and of those of the parent planets as well, are expected to be drastically improved.

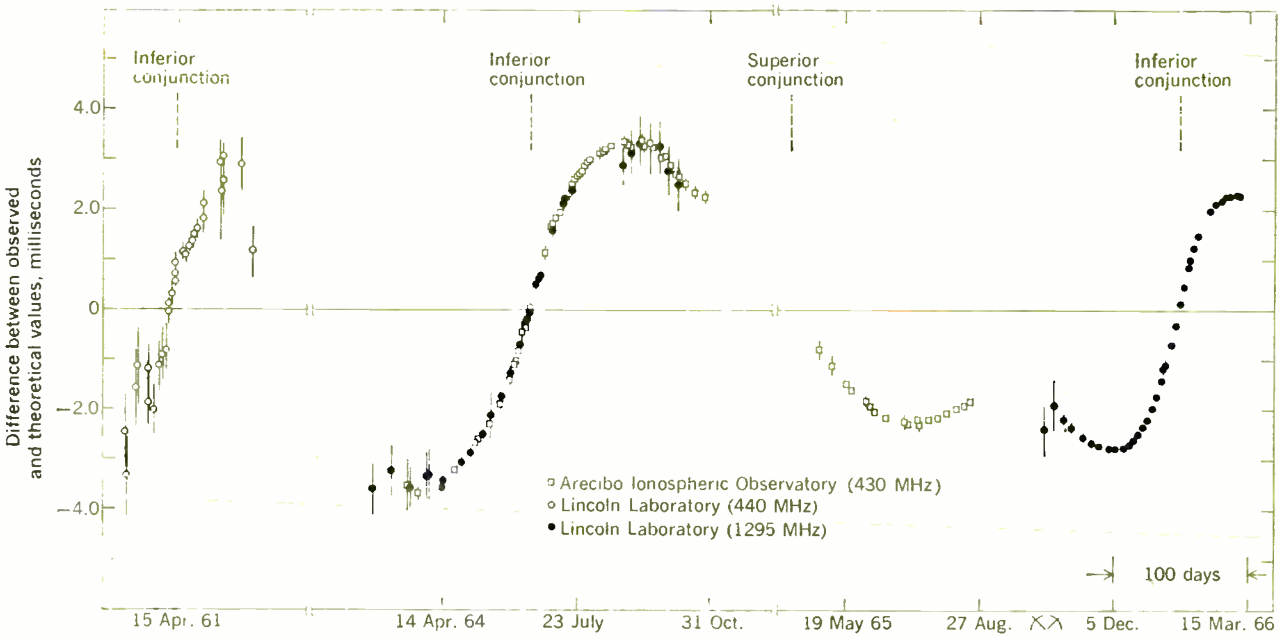
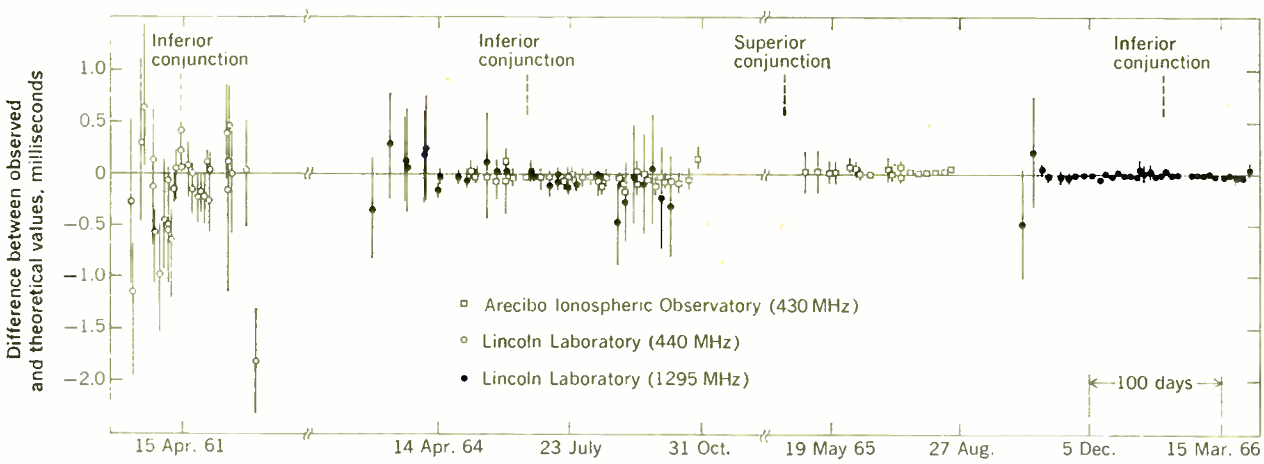


FIGURE 4. Comparison of observed earth–Venus time-delay measurements with theoretical values based on JPL ephemeris tapes.[22]

FIGURE 5. Comparison of observed earth–Venus time-delay measurements with theoretical values based on a least-mean-square fit to 364 radar observations of Venus and Mercury.[23] Note the decrease in measurement errors with time.



Planetary rotations

Radar observations can also be used to determine planetary rotation vectors. Before discussing the results obtained, I shall describe the techniques employed in such determinations.

Delay-Doppler mapping. In the preceding section, reference was made only to the time delays and Doppler shifts introduced by reflections from the subradar point on the target planet (that is, the point on the surface intersected by the line from the radar site to the center of the planet). A planet is, of course, an extended target—very large compared with the radar wavelength—and one may assume that each small element of the surface reflects independently of the others. Each element of surface will therefore reflect an incident wavefront at a particular time delay and will impart a particular Doppler shift, depending on the component of its velocity along the direction of propagation of the incident radar wave. These facts embody the fundamental principle of delay-Doppler (i.e., "range-Doppler") mapping.[26] To understand this principle in greater detail, consider the reflection from a planet of an essentially monochromatic, very short radar pulse. At the receiver, signal energy will be received over a time interval defined by twice the radius of the target, each part of this interval being associated with the reflections from a particular ring (or annulus) on the target. As viewed from the radar, the target appears to have a certain rotation. Simple geometric arguments show that for a distant target all surface points lying in a plane that is parallel to the one containing the radar site and the target's apparent rotation axis will impart the same Doppler shift to the

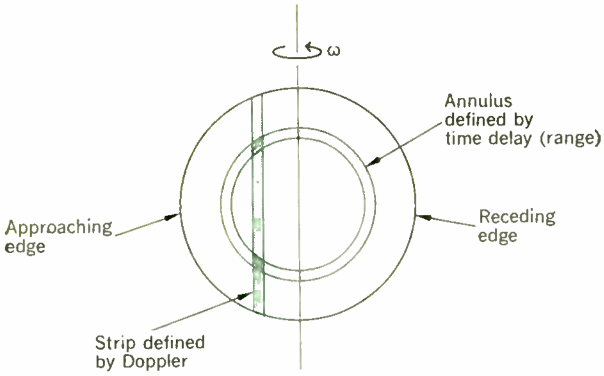


FIGURE 6. Principles of delay-Doppler mapping. Contours of constant time delay and constant Doppler shift are shown for a hypothetical pair of values. Doubly shaded regions indicate the two areas having the same frequency and time-delay coordinates.

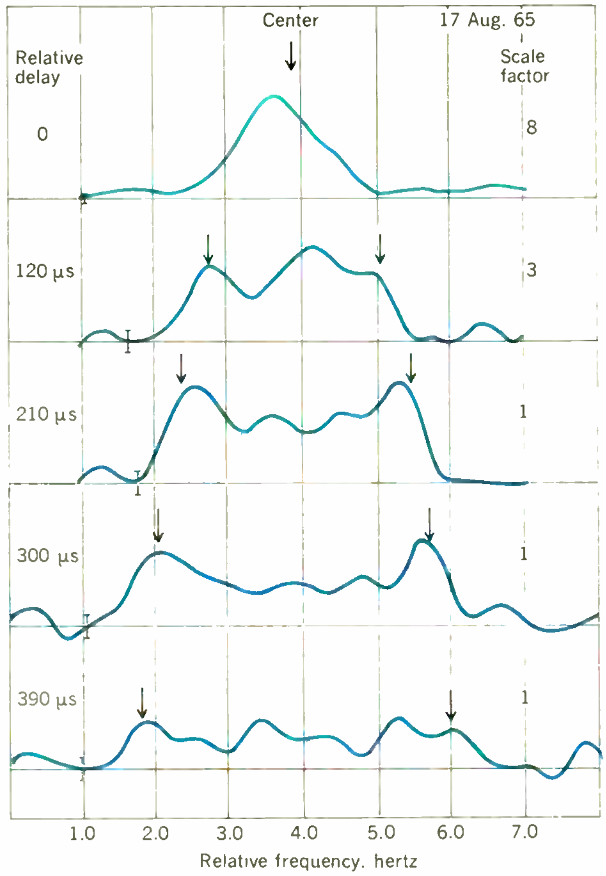


FIGURE 7. Spectra of radar echoes from Mercury as a function of delay relative to the subradar point. Amplitudes have been scaled inversely by the factors listed in the right-hand column. Transmitted pulses were 100 μs long; thus the spectra are essentially independent of each other. Error bars representing plus and minus one standard deviation of the measurement noise are shown near the left edge of each spectrum. The arrows indicate the expected positions of the edges of the spectra assuming a sidereal rotation period of 59 days with the rotation axis directed normal to Mercury's orbital plane. The described spectra were obtained at a frequency of 430 MHz by the Arecibo Ionospheric Observatory.[34]

incident wave. Each "strip" on the surface is associated with a unique Doppler shift, and each annulus with a unique time delay, the ensemble yielding a delay-Doppler map of the planetary surface, as shown in Fig. 6. The characteristics of these maps are somewhat unusual in that the transformation from spherical to delay-Doppler coordinates is essentially two to one and causes a two-fold ambiguity in the mapping for points not lying along the equator. On the equator the Jacobian of the transformation from spherical coordinates is singular; at the intersection there, the delay annulus is parallel to the Doppler strip, and thus the common area is greatly enlarged. This singularity plays an important part in the determination of planetary rotation rates.

Estimation of rotation vectors. The angular velocity of a planet as seen from the radar is composed of two parts: (1) the contribution of the intrinsic, or sidereal, rotation of the planet; and (2) the contribution due to the relative motion of the radar site and the center of the planet. The second contribution can be understood more clearly by considering a hypothetical case in which the target planet has no intrinsic rotational (as opposed to orbital) angular velocity. As the earth moves relative to the planet in space, the radar views the latter from differing aspects; that is, to the observer on earth, the planet appears to be rotating.

How can the quantitative characteristics of planetary rotations be determined from radar observations? One method employs a set of spectral bandwidths, each associated with the echo from a distinct annular region on a particular day of observation. (Experimentally, the bandwidth is determined by the difference in frequency of the peaks at the limbs of the spectrum, these being caused by a large common area of the intersecting delay and Doppler contours; since the noise spectrum is flat over the spectral region of interest, the peaks at the limbs have the highest signal-to-noise ratios.) At each orbital position, any given bandwidth is proportional to the projection on a plane perpendicular to the radar line of sight of the vector sum of the sidereal angular velocity of rotation of the planet and the apparent angular velocity due to the relative orbital motions. From the series of bandwidth measurements encompassing a number of different orbital positions, one can resolve all ambiguities and determine the three scalar parameters describing the planet's sidereal rotation vector.

Another complementary method of estimating the sidereal rotation vector depends upon the presence of identifiable features in the delay-Doppler maps of the planetary surface. The change with time of the location on the map of any given feature will, of course, depend on the rotation vector. By employing the same type of analysis as outlined previously, one can use a series of such maps to estimate the rotation vector as well as the surface latitude and longitude of each identifiable feature. One-dimensional maps (for example, power versus delay or power versus frequency) can also be used. The main advantage of this method is that, aside from statistical averaging, the error in the determination of the rotation period will decrease as the inverse of the total time interval spanned by the data. The major disadvantage is the necessity for the somewhat subjective identification of the same features on a sequence of delay-Doppler

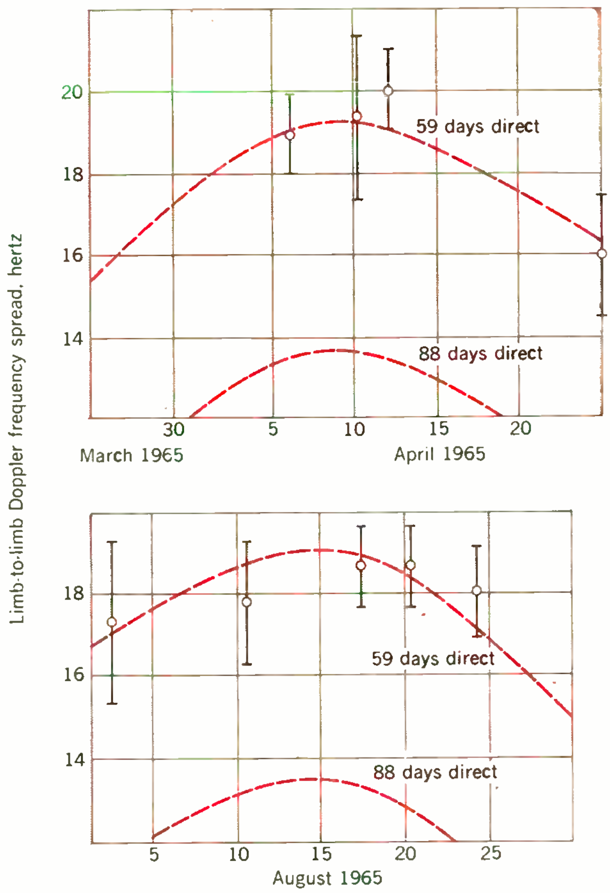


FIGURE 8. Determination of Mercury's rotation period. Radar data similar to those shown in Fig. 7 were used to infer the bandwidths corresponding to reflections from the edges of the apparent disk. In the least-squares solution the rotation axis was constrained to lie perpendicular to Mercury's orbital plane because of the limited accuracy of the available data. Removing this constraint will change the estimated rotation period by less than the quoted error of plus or minus 3 days.[34]

(or one-dimensional) maps of the surface. The possibility of incorrect identification can be guarded against by comparing results with the wholly objective determination based on the bandwidth data.

The radar methods cannot yet compete in accuracy with optical determinations of planetary rotation rates, except for Mercury and Venus. These notable exceptions give the radar methods of estimating axial rotations their great importance.

Rotation of Mercury. Because of Mercury's small size, low reflectivity, and proximity to the sun, its markings are very difficult to observe telescopically and are even more difficult to photograph. The optical observations have consequently not always been noted for their reliability. At the start of the 19th century, drawings of the surface led Bessel[27] to the conclusion that the rotation period was almost precisely 24 hours. Although some astronomers remained skeptical, many found it especially appealing esthetically to think of Mercury, like Mars, as having approximately the same length of day as the earth. This "fact" was not finally discredited until the 1880s, when extended series of visual observations by Schiaparelli[28] convinced most astronomers that Mercury was rotating slowly, with a period equal to its orbital period of 88 days. The analogy with the moon's motion about the earth was very pleasing, and until the spring of 1965 all observations, without exception, were interpreted as being consistent with the 88-day rotational period.[10, 29–32] Then when it became possible to make delay Doppler maps of the surface with radar, the results (Figs. 7 and 8) showed the sidereal rotation period of Mercury to be 59 ± 3 days.[33, 34] Re-examinations of all the published drawings and the few published photographs disclosed that most, but not all, of them were consistent with a 59-day period[35, 36] precisely because 59 is essentially two thirds of 88.[36]

Except for Schiaparelli's, apparently almost all of the optical observations were made at intervals corresponding in essence to even multiples of Mercury's orbital period and hence to integral multiples of 59 days (more precisely, 58.65 days). No later observers had considered the possibility of ambiguity.

Perhaps these reinterpretations of the optical data should be treated cautiously. The references in the literature to extended series of observations of Mercury—coupled with the facts that no prominent marking on Mercury was ever noted as being in the "wrong" location and that the other hemisphere was never recognized as such—provide powerful evidence for considering all drawings of the surface to be suspect. Prudence probably demands that one look to future rather than past observations for a reliable reduction in the present uncertainty given by the radar determination of Mercury's axial rotation period. Since Mercury, like Venus, exhibits features when observed by radar, one may expect radar observations to provide a quite precise determination within a very few years.

How may one understand Mercury's rotation? It was first suggested[37] that for the observed rotation to be stable only the solar tidal torque could be important. For stability, of course, the average torque exerted on Mercury must vanish. The solar tidal torque will tend to oppose the apparent rotational motion of the planet as seen from the sun, this motion being given by the difference between orbital and spin angular velocities. Because of the large eccentricity of Mercury's orbit, the spin angular velocity will be less than the orbital near perihelion but greater elsewhere. The tidal torque will therefore change sign twice during an orbital period and can yield a zero average. A deviation of Mercury's inertia ellipsoid from axial symmetry (that is, a difference between the two permanent principal moments of inertia lying in the equatorial plane) leads to a further torque, which could produce a resonance rotation.[36, 38, 39] Resonances occur when a planet makes an integral number of half rotations during one orbital revolution. The sidereal spin period P_s and the orbital period P_o therefore satisfy the simple relation $P_s = 2P_o/k$, with k an integer. The solar torque exerted on the permanent asymmetry, acting in concert with the tidal torque, could cause Mercury to be trapped into a $k = 3$ resonance spin state.[36, 38, 40]

Analysis shows that for reasonable assumptions about the magnitude of the tidal torque, the asymmetry in the inertia ellipsoid required for stability in this $k = 3$ state (see Fig. 9) is very modest: several orders of magnitude less than the observed asymmetry of the moon.

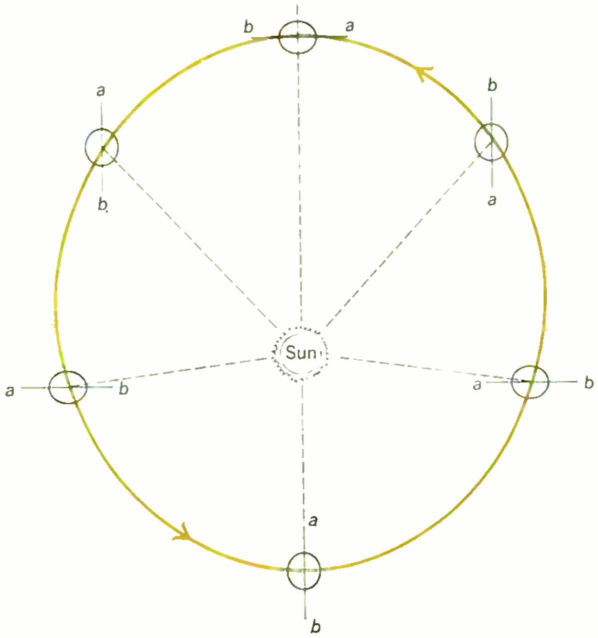


FIGURE 9. Expected orientation of Mercury's axis of minimum moment of inertia as a function of orbital position for the $R = 3$ resonance spin state. (The sidereal spin period $P_s = 2P/3 \approx 58.65$ days.)

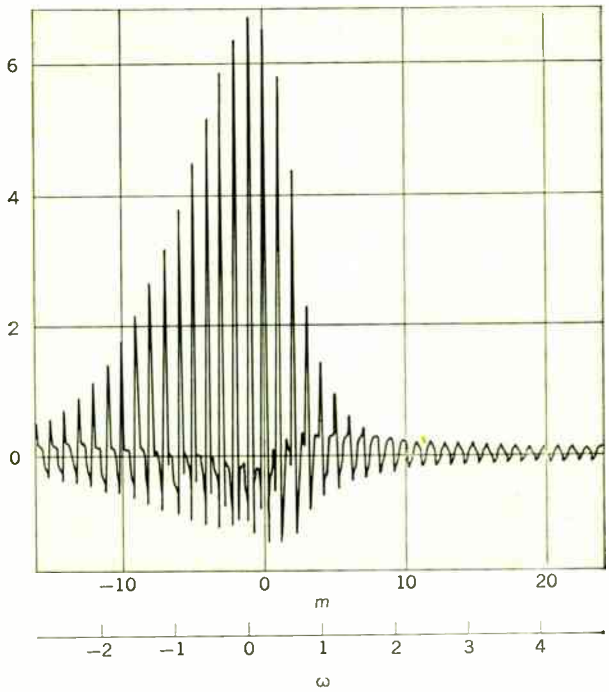


FIGURE 10. Average torque exerted by earth on Venus as a function of the spin angular velocity.

A detailed study of the dynamics shows that for the resonance rotation to be asymptotically stable it is also necessary (at least to first order in the perturbations) that the derivative of the average tidal torque with respect to the spin angular velocity be negative.[41] This condition is satisfied for Mercury with its present value of orbital eccentricity. If the eccentricity were below about 0.19, the stability could be disrupted depending on the form of the tidal torque.[41] A very precise determination of both the instantaneous angular velocity and the orientation of Mercury's inertial ellipsoid would allow the equatorial asymmetry of the latter and the magnitude of the tidal torque to be determined. Present radar measurements are far too crude to be useful for this purpose.

Presumably, Mercury's primordial rotation was not near the resonance value of 58.65 days. The planet was most likely spinning much faster either in a direct or a retrograde sense. How then could the rotational motion have evolved to its present state? The spin state would have had to pass the resonance barriers on either side ($k \leqslant 2$ or $k \geqslant 4$). Penetration of the higher resonances is almost guaranteed because of the high orbital eccentricity required for capture. The conditions for the penetration of the $k = 2$ resonance barrier that would lead to capture in the $k = 3$ state are difficult to establish. Nevertheless, preliminary results indicate that such conditions exist[41] but are very improbable; therefore, one cannot yet rule out the possibility that Mercury's rotational motion was originally retrograde.

Rotation of Venus. Because Venus has a dense cloud cover, no reliable estimates of its rotation rate were possible prior to radar measurements. In 1962, measurements at JPL[42,43] disclosed that the rotation was definitely retrograde, with a period of about 250 days. The earlier radar measurements had established only that the rotation was slow, although the possibility of retrograde rotation had been noted.[4] Recent determinations[34,44] show the rotation period to be within a day or two of 243.15 days—a most surprising result, since for this period Venus would present the same face to the earth at every inferior conjunction. As seen by an earth observer, Venus would appear to rotate precisely four times between close approaches. [Were the period 250.5 days (retrograde), Venus would present the same "face" to Jupiter at every close approach to these two planets; the view of Venus from Mercury would repeat at alternate close approaches for a spin period of 238 days.]

How may one explain the anomalous rotation of Venus? A satisfactory theoretical description must provide answers to two questions: (1) How did the axial rotation evolve to the neighborhood of its present state? (2) Is a spin state that is locked to the relative orbital motion of the earth and Venus stable? First one must start with an assumption about the primordial spin state. If one considers it to have been direct, then the low orbital eccentricity (which, according to the best available orbital calculations, does not change appreciably because of planetary perturbations) implies that a resonance lock, with Venus always presenting the same face to the sun, would have resulted were the solar tidal torques sufficiently large. Such a lock would be very strong indeed; many continuously acting and possibly destabilizing torques have been considered[41] and none appears strong enough to disrupt the resonance and to produce a retrograde rotation.

One rather fanciful approach is to invoke a Venus–asteroid collision; an asteroid some 200 km in diameter could transfer the angular momentum necessary to convert the synchronous direct rotation into a retrograde

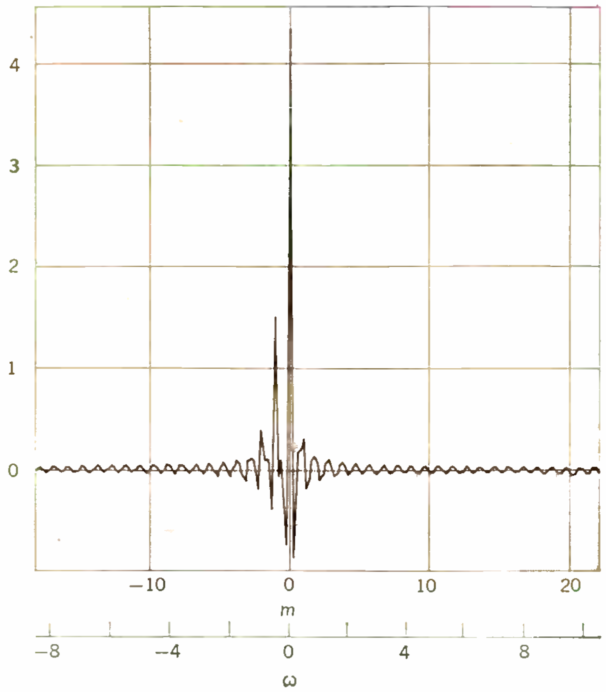


FIGURE 11. Average torque exerted by Jupiter on Venus as a function of the spin angular velocity.

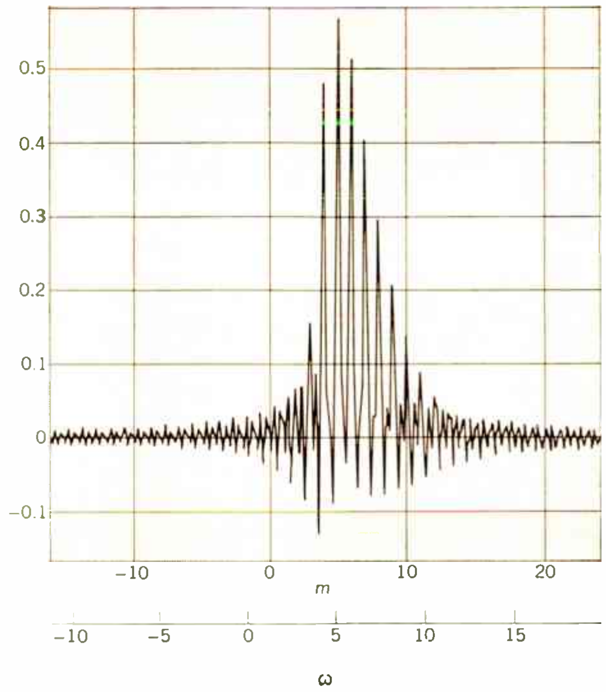


FIGURE 12. Average torque exerted by Mercury on Venus as a function of the spin angular velocity.

spin with about the observed period. Analyzing such a collision in detail is not feasible, but one might expect the surface to exhibit traces of such a monumental impact. Although most probably unrelated, a large region on the surface of Venus does have anomalous backscattering characteristics.[45,46]

Considering the rather primitive state of the theories of the origin of planets, one may assume, alternatively, that the rotation of Venus was originally rapid but retrograde. One can then imagine that, after being slowed by tidal torques, Venus' rotational motion became locked to its orbital motion in the resonance state $k = -2$, corresponding to a retrograde rotation with a period of 224.7 days. Such a capture would require an orbital eccentricity of about 0.1 and a fractional difference in principal equatorial moments of inertia comparable to or larger than that of the moon.[41] Analysis of this capture process of course is equally applicable to conditions following a hypothetical Venus–asteroid collision that disrupts a $k = 2$ resonance and places the spin state near the $k = -2$ resonance. In addition, such a collision could have enlarged the axial asymmetry of Venus' inertial ellipsoid. Escape from the $k = -2$ resonance state could have occurred if either the orbital eccentricity decreased sufficiently or the viscous component of the tidal torque ceased to be effective.[11] Inasmuch as the rotation of Venus continues to slow down after escape, the first earth–Venus resonance state that is encountered is the resonance state corresponding to a rotation period of 243.15 days.

Resonances involving a planetary torque occur for spin periods such that the axis of a principal equatorial moment of inertia makes the same angle with the Venus–planet line at successive close approaches.[41,47] Since dynamically one cannot distinguish between one "end" or the other of the principal axis pointing in a given direction, this resonance condition can be phrased as follows: From the time of one close approach of Venus and a planet to the time of the next, Venus must rotate through an angle Δv plus an integral number of half revolutions, where Δv represents the difference (modulo 2π) between the true anomaly of Venus at the beginning and at the end of this (synodic) time interval. The spin angular velocity ω (in radians/radian) at resonance is equal to

$$1 + [(m/2) - q]\,|1 - n_p|$$

where m is an integer (positive, negative, or zero), n_p is the ratio of the mean motion of the planet to that of Venus, and q, for example, is 2, 1, and 0 for earth, Jupiter, and Mercury respectively.

At first glance one might think that the torque exerted by a planet on any axial asymmetry of Venus' inertia ellipsoid would be negligible compared with the corresponding torque exerted by the sun. But in the limit of circular orbits it is clear that to first order at least, the effect of the solar torque will average to zero. Furthermore, even for nonzero orbital eccentricity, the solar torque will tend to average out for the observed spin rate. (Note that at every fifth close approach, the earth and Venus return to almost identical spatial positions.) Although realizing that second-order effects of the solar torque must be considered before a reliable conclusion may be drawn, one can nevertheless consider the rotational motion of Venus to be influenced solely by a solar tidal torque and by a planetary torque exerted on an axial asymmetry of the inertia ellipsoid. To illustrate the relative importance of the various resonances, the planetary torques, averaged over a synodic period, are shown in Figs. 10, 11, and 12, for earth, Jupiter, and Mercury, respectively, as a function of m and ω; the ordinate units, though arbitrary, are consistent throughout the three figures.

In Fig. 10, the retrograde rotation with a period of 243.15 days, corresponding to $m = -6$ (that is, to four complete axial rotations of Venus between inferior conjunctions as seen by an earth observer), appears rather undistinguished relative to the neighboring resonances, except for its proximity to the $k = -2$ sun–Venus resonance. In Figure 11, the retrograde rotation with a period of 250.5 days, corresponding to $m = -2$, yields an average Jupiter–Venus torque about an order of magnitude smaller than the value deduced from the neighboring earth–Venus resonance. Mercury exerts an even smaller average torque.

The detailed study of the dynamics of the rotational motion in the vicinity of a planet–Venus resonance is quite complicated. Nonetheless, a simple analysis[41, 47] allows one to conclude with reasonable confidence that for the retrograde rotation with a period of 243.15 days to be asymptotically stable, the fractional difference in Venus' principal equatorial moments of inertia must be relatively large, perhaps substantially greater than 10^{-4}. (The corresponding value for the moon is 2×10^{-4}.)

If the other necessary conditions are also considered, it becomes clear that the existence of a stable earth–Venus resonance rotation is indeed a most surprising phenomenon. A stable Jupiter–Venus resonance rotation would be even more surprising. How Venus evolved to its present spin state and how long it may be expected to remain there must still be considered very largely unanswered.

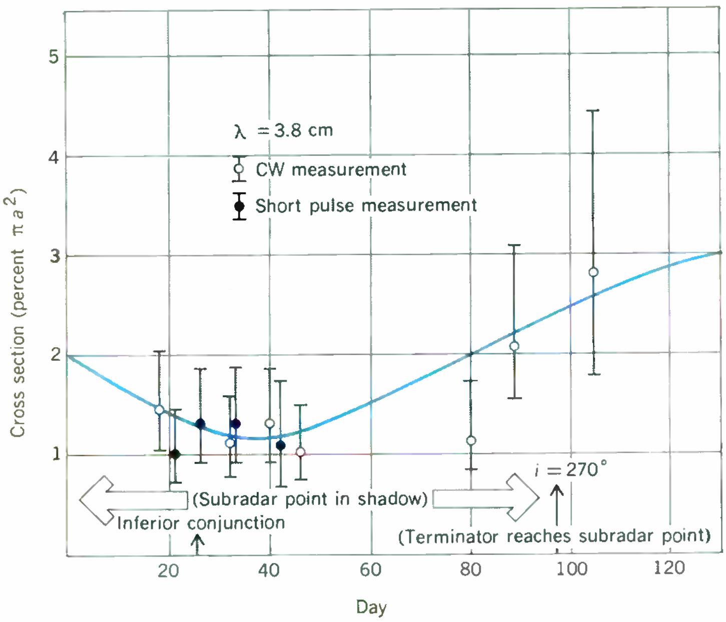


FIGURE 13. Time dependence of the observed radar cross section of Venus at 7750 MHz. The smooth curve drawn through the data has little significance (see text).

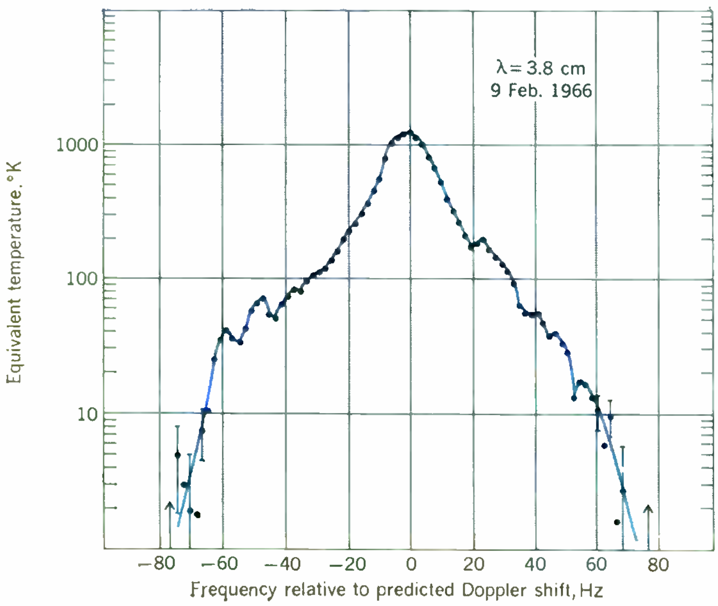


FIGURE 14. Spectrum of 7750-MHz radar waves reflected from Venus. Features correspond to those observed at lower frequencies, thus establishing that the X-band reflections are predominantly from the surface.

Interplanetary medium

As mentioned previously, interplanetary radar observations may be employed to explore the properties of the medium present between the radar site and the target planet. The extreme radar-system sensitivity required to obtain useful information about the intervening medium has severely limited the applications. The few deductions so far possible are nonetheless of particular importance. I will concentrate here on the evidence that X-band radio waves are heavily absorbed by the atmosphere of Venus.

At frequencies from 430 MHz to 2388 MHz, the radar cross section of Venus has been repeatedly observed to lie between 10 and 15 percent of its geometric value.[17] Yet observations at Lincoln Laboratory in 1964 at 8350 MHz yielded a cross section of only 1 percent.[48] This experiment was repeated in 1966 when a much higher signal-to-noise ratio was available.[49] The observed cross section is shown as a function of time in Fig. 13. The solid curve drawn through the points implies that the cross section may be a minimum at inferior conjunction (when the subradar point corresponds to midnight on Venus) and increases as the subradar point passes into sunlight.

Observations made more recently deflate this implication; the cross section appears to behave somewhat erratically with time and may merely reflect changing surface conditions at the subradar point. The possibility of the frequency dependence of the cross section being explained completely by peculiar surface properties, rather than at least partly by atmospheric absorption, seems remote; the change in cross section with frequency is too rapid. The establishment of Venus' atmosphere as an important absorber of X-band radiation is of great interest and places some severe restrictions on model atmospheres.

One might wonder whether the reflections of X-band signals emanate from the atmosphere itself rather than from the surface of Venus. The 1966 experiment establishes conclusively that the surface is the primary reflecting agency. First, since the peak of the echo spectrum lies precisely (to within 0.5 Hz) at the position of the expected peak for reflections from the surface, if particles in the atmosphere were the major contributors to the backscattered signal, they could have radial velocities no greater than about 1 cm/s. Second, the time delay for the reflected energy coincides to within the measurement error of 1.5 km, with the simultaneously measured delay to the subradar point at 1295 MHz[50]; thus, a very stringent upper limit is set upon the altitude of any major atmospheric contribution to the detected echo. Third, the spectra exhibit features (see Fig. 14) that correlate remarkably well with features observed at lower frequencies, where the reflections are definitely known to be from the surface.

Another Venus radar experiment undertaken in 1966 utilized the opposite end of the radio spectrum to explore the properties of the plasma between the earth and the surface of Venus.[51] Simultaneous measurements of time delays to the subradar point made with a Lincoln Laboratory facility, operating at 1295 MHz, and the National Bureau of Standards facility at Jicamarca, Peru, operating at 50 MHz, enabled the plasma effects on the delays to be deduced. The results will be checked and perhaps improved by comparing the phases of the echoes from a number of different frequencies in the neighborhood of 50 MHz that were transmitted nearly simultaneously. The integrated electron density between the radar site and the surface of Venus is the physical quantity obtained in the experiment and can be used to determine an upper bound on the electron content of Venus' ionosphere. Preliminary results indicate that this content, at least at local midnight, is no higher than earth's, since the total observed differential delay (≈ 100 μs on most days) is well accounted for by the interplanetary plasma and the earth's ionosphere. Subtracting the latter contribution and assuming a plasma density inversely proportional to the square of the distance from the sun yields a density at the earth's orbit of about 10 electrons per cubic centimeter. It will be interesting to compare this result with space-probe plasma measurements made between earth and Venus at the same time.

Epilogue

It has sometimes been stated that Venus is the mystery planet; there are other claims that Mars, Mercury, or Jupiter should be so described. Most likely, all planets (certainly not excepting earth) qualify in one respect or another. New experimental information about a planet always seems to raise more questions than it answers. There is little danger that future radar observations will reverse this trend.

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Sir Charles Wheatstone did not actually invent the famous bridge circuit that perpetuates his name in technical lore and literature, but he did make many other important contributions to the technology. The present article outlines the life of this man of many talents and interests, with emphasis on his career as an inventor and scientist.

Except, perhaps, for the well-known bridge circuit that bears his name—and which, paradoxically, was not his creation—Sir Charles Wheatstone is little remembered today. However, in his lifetime (1802–1875) he enjoyed a considerable amount of acclaim, and associated with the leading scholars, artists, statesmen, and industrialists of Victorian England—and, although his fame has not endured, many of his contributions to science and technology have.

Portrait from *The Illustrated London News*, vol. 67, p. 459 (1875). Photographic copy courtesy of General Aniline & Film Corporation.

Beginning of a career

Charles Wheatstone was born in Gloucester, England, in 1802, moving to London with his family when he was four years old. He was a precocious child, having learned to read while still at Gloucester, and he attended private schools in London until he was about 14. He then was apprenticed to a namesake uncle who manufactured musical instruments. Young Charles showed little promise at learning the trade, preferring to go off by himself to read books instead of pursuing his assigned tasks, but his uncle apparently accepted this in good grace, and Charles' father, an accomplished musician and something of a scholar, permitted Charles to devote three years to independent studies in science, literature, and languages. His subsequent achievements show that he had the necessary powers of concentration and self-discipline to profit greatly from such an opportunity. With his studies behind him, Wheatstone returned to the musical instrument shop and in a short time was conducting experimental investigations in acoustics. As an authority on acoustics and music theory, he was more of an asset to his uncle's business than he would have been had he successfully continued in his initial role as an apprentice.

One demonstration, first conducted by Wheatstone in 1821 and repeated later with variations, that attracted a great deal of attention, featured two musical instruments. The two instruments appeared to be decoupled, being in separate rooms of a building, but actually they were very strongly coupled by means of a taut metal wire, or thin rod, that connected their resonant chambers, or sounding boards. When one instrument was played, sound was conducted to the other through the metal conductor, and deceptive sensations were experienced by the onlookers, who saw only one instrument but heard a duet. Various instruments were used—pianos, harps, lyres, guitar—sometimes two of a kind, sometimes two different instruments. The first experiments featured antique lyres. A lyre used in this manner was popularly called an "enchanted lyre," and Wheatstone also used this term to designate the class of demonstrations that he developed from the experiments.

Another of Wheatstone's experiments involved the "kaleidophone," a name he coined for a vibrating rod clamped at one end. There were several forms of the kaleidophone—steel rods with variations both as to cross section and linear shape, with one or more silvered glass beads mounted on the ends. When a rod was excited into oscillations, the motion of the glass bead (or beads) on its free end presented a pattern to the eye through the persistence of visual perception.[1]

In this period Wheatstone wrote a number of papers on the transmission of sound, the sympathetic vibrations induced in acoustic resonators, and the fundamentals of harmony. Between the ages of 17 and 26 he also carried out studies to relate the loudness of music to amplitude of vibration and the quality of musical tone to harmonic content. Although they were not as fundamental and important as his later studies, they were of sufficient interest to earn him a reputation as an outstanding young scientist.

When Wheatstone was only 21, his ten-page monograph, "New Experiments in Sound," was read to the Academy of Sciences in Paris by M. Arago, and it was published in Thomson's *Annals of Philosophy* in 1823 and reprinted in leading French and German journals the same year. At about the same time, the celebrated Professor Oersted of Copenhagen came to the Wheatstone music shop to meet Charles and witness his experiments.

Some practical devices

Although Wheatstone had a keen interest in scientific principles, he also maintained an appreciation for the practical utilization of science, and whether he was pursuing an abstract idea or inventing a new gadget, he displayed a rare ingenuity for combining mechanical skill with an understanding of physical and mathematical principles.

By the time he was 34, Wheatstone had begun to investigate the problems and possibilities of submarine telegraphy.[2] Four years later he completed what he felt

Sir Charles Wheatstone—forgotten genius

Although the results of Wheatstone's scientific work have endured; his personal fame has not. However, during his lifetime he enjoyed a reputation as one of the leading scientists of the period

B. R. Gossick *University of Kentucky*

were satisfactory design studies, and was ready to discuss, before the Railway Committee of the House of Commons, the practicability of installing a submarine line between Dover, England, and Calais, France. Following the development of a prototype model of a land telegraph system between Camden Town and Euston Station (purported to be accomplished in collaboration with Cooke) which he demonstrated for the Prince Consort in 1843, he was able to demonstrate submarine telegraphy in an 1844 experiment in Swansea Bay during which he transmitted signals by telegraph between a boat and Mumbles Lighthouse.[3]

Measurements of time were a preoccupation with Wheatstone. He invented an electromagnetic clock[1] in 1840 and another clock (1848) that used the polarization of skylight to determine the solar time; its advantage over the ordinary sundial was that it could be used on a cloudy day.

The articulation of human speech was another subject that received his attention, and he went so far as to construct a speaking machine after the descriptions of de Kempelen.[4] A study on the physiology of vision, which he carried out in 1838, resulted in the invention of the stereoscope.

In all, Wheatstone's ingenuity is evidenced by his invention of more than 140 automatic instruments, devices that he lived to see put into use.

Professor Wheatstone of King's College

When placed in proper perspective, Wheatstone's early studies on the kaleidophone became important extensions of the work of Chladni, and it was probably through having conducted them that he was able later, at the age of 31, to perform a detailed theoretical analysis of the Chladni figures, showing them to be a superposition of normal modes.[4] When he was only 32, he was appointed a professor of experimental philosophy at King's College in London, and two years later was elected a Fellow of the Royal Society.

Within a year after receiving his King's College appointment, Wheatstone reported an experimental study that had important consequences, in spite of his failure, and that of others, to interpret the results. Posing the objective of measuring the speed of propagation of an electromagnetic impulse along a conductor, Wheatstone invented a method whereby a rotating mirror was used to observe the timing of sparks across three closely spaced gaps, inserted at the middle and both ends of a 0.8-km length of wire mounted on an insulating frame in the Gallery in Adelaide Street, King's College. This instrument had a resolving time of less than one microsecond.[1] Its attainable accuracy should have been at least one part in 1000 in principle, because the speed of rotation of the mirror was determined by the pitch of a musical tone created by the rotation, and the measurement of frequency by this method by one with Wheatstone's knowledge of music and acoustics should have been that precise. (It is interesting to note that he considered a modification of this instrument to be used as a stroboscope, an idea implicit in his writings and unpublished notes.[2]) The velocity of propagation in this case was measured with great accuracy, and turned out to be about 1.5 times the velocity of light *in vacuo*. The coupling of the wires given by the particular geometric arrangement determined the velocity as a special case that could not be treated by electromagnetic theory as it stood then. Fifteen years later, Fizeau used a variation of Wheatstone's rotating mirror to measure the velocity of light.

Wheatstone also carried out two other important experiments in his first year as a faculty member at King's College. Although Wollaston, Bunsen, and Fraunhofer had discovered lines in the emission spectra of elements, it was Wheatstone who demonstrated that these lines could be used as a specific means for chemical identification, and he did this by utilizing the spark spectrum of various metals.[4] His other experiment verified Bernoulli's theory of the sound vibrations of a pipe open at both ends, i.e., "that in the fundamental sound of a tube, open at both ends, the portions of air on opposite sides of the center of the tube move in opposite directions to each other." A flexible open cylindrical tube was excited into sympathetic vibrations by a plate made to oscillate in its fundamental mode either by stroking with a violin bow or striking with a hammer. The opposite ends of the tube were first arranged so that the vibrations of the plate were exactly out of phase at the two ends; no augmentation of the original sound was heard. The ends then were rearranged so that the plate vibrated at both ends exactly in phase—and the augmentation of sound was quite evident.[4]

In 1843 Wheatstone accepted an invitation from the Royal Society of London to deliver the annual Bakerian lecture. He chose as his title, "An Account of Several New Instruments and Processes for Determining the Constants of a Voltaic Circuit." While looking into the feasibility of telegraphy, by studying the behavior of electric circuits extended over great distances, he had employed a variety of methods to determine the interrelationships between current, voltage, and resistance. Although the basic methods were not new, Wheatstone had added his own refinements. He summarized these experimental methods in his Bakerian lecture, which was a review embellished by the presentation of some new details. Wheatstone cited several investigators who had confirmed Ohm's law—Fechner, Lenz, and Pouillet. In describing rheostats of his own design, Wheatstone mentioned that similar devices had also been used by Jacobi and Poggendorff. Wheatstone's methods were of two types: (1) the substitution method, in which the deflection of a galvanometer was made the same by adjusting a calibrated rheostat which replaced an unknown resistance; and (2) the differential method, in which a null reading on a galvanometer was produced by adjusting a calibrated rheostat.

A decade earlier the Bakerian lecture had been given by Samuel Hunter Christie (1784–1865), F.R.S., who was born in London and was a member of the mathematics faculty (1806–1854) at the Royal Military Academy at Woolwich (a suburb of London). In his lecture Christie described his experimental studies to determine the relative conducting power of a number of metallic elements. He made no reference to the work of Ohm, but he did refer to the studies of Davy, Becquerel, Cummings, and Harris. Whereas Davy and Becquerel had studied the conducting power of metals by using voltaic piles, Cummings had used thermoelectricity, Harris had used electricity from a "machine," and Christie employed a new effect discovered by Faraday—current induced by a magnet. Christie used two differential circuits, which were described in Wheatstone's Bakerian lecture ten years later. One of these differential circuits has become known as the "Wheatstone bridge." Whereas Christie determined the relative conducting power of certain metals with the bridge circuit, Wheatstone exploited the capabilities of the bridge to determine resistance, and since he set the precedent for using the bridge in the way in which it has since been used, it is understandable that in time it came to bear his name. Wheatstone did not cite Christie in the transcript of the Bakerian lecture that appeared in the *Philosophical Transactions*. Apparently Christie's prior work was brought to his attention later. He then added a footnote to his file copy giving full credit to Christie, and this appears in the version of the Bakerian lecture contained in his collected papers.[3,4]

Wheatstone, the man

Charles Wheatstone was diffident by nature, and lecturing was a burden that he was never able to carry effectively. He rarely gave formal lectures, even at King's College, where his activities centered about research. Nevertheless, in a small gathering, among those who shared his numerous interests, he was considered a brilliant conversationalist. He was methodical, quiet in a crowd, but articulate and excitable among intimate acquaintances. He enjoyed lifelong friendships, and his domestic life was said to be tranquil. Although he was mild mannered in his dealings, it was not through an inability to uphold his convictions. He was sometimes mulishly dogmatic, as on the occasion when, refereeing for the Royal Society, he rejected Joule's paper that established the first law of thermodynamics. Furthermore, he could be ungracious; in 1867 he refused the Albert Medal of the Royal Society of Arts because the same award had been offered to Cooke. Thus, quite a range of characteristics were attributed to Wheatstone, as might be expected for a complex man of genius.

During his career, Wheatstone served on a number of important committees of government and industry. He was appointed to the Board of Trade Committee on The Atlantic Cable[1] in 1859, he became a member of the board of directors of the Universal Private Telegraph Company[5] in 1863, and he served on the Scientific Committee of the Atlantic Telegraph Company[6] in 1864. He also served on the Ordnance Select Committee of the British government.[7] In recognition of Wheatstone's many services, he was knighted in 1868 by the government of Lord Derby.[1]

He received medals from the Royal Society in 1840 and 1843,[1] and was awarded honorary doctorates by Oxford University (1862), Cambridge University (1864), and Edinburgh University (1869). He was made a Chevalier of the French Legion of Honor in 1855,[8,9] and an honorary member of the Italian Society of Sciences in 1867.[1] In 1873 he was made a Foreign Associate of the Academy of Science (France),[8,9] and awarded the Ampère Medal by the French Society for the Encouragement of National Industry. In 1875 he was elected an honorary member of the Institution of Civil Engineers.[3]

In spite of his relative lack of fame today, Wheatstone's life was a successful and productive one. His papers, and the scientific instruments he bequeathed to King's College, reveal his mastery of invention and experimentation, his skill in reducing a problem to its essential parts, and his flair for designing simple instruments to probe the ways of nature.

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Directions for speech research

Penetrating research has given speech investigators a real handle on problems of speech acoustics and production. Now, the experts say, the same kind of research needs to be applied to human speech perception, a still uncharted area

This report on a panel discussion during a recent conference on speech research reveals some of the dominant problems of present speech investigations. Experts from diverse speech fields talked about the need for better models, the problem of finding applications of automatic speech recognition, the need for deeper studies of human speech perception, and the effects of context. The search for invariants in speech continues. Overall, the discussions reveal that there has come about, for both practical and theoretical reasons, a need to treat speech perception with the same emphasis that acoustic analyses and speech production are receiving.—N. L.

Just a year ago, at the IEEE International Convention, a group of experts from diverse activities of speech research discussed the *nature* of man's speech.[1] Their discussions ranged over both cultural and technical questions, speculated rather freely about the long-range future, and, in general, were of a philosophic character. At a recent conference on speech communication and processing, held in Cambridge, and sponsored jointly by the Air Force Cambridge Research Laboratories and the IEEE Audio and Electroacoustics Group, the highlight of the three-day technical sessions was a similar panel discussion on problems of speech research.

The panel discussion, chaired by Dr. J. L. Flanagan of the Bell Telephone Laboratories, included Dr. Franklin S. Cooper, Haskins Laboratories, New York; Prof. Gunnar Fant, Royal Institute of Technology, Stockholm; Dr. Adrian Fourcin, University College, London; Prof. Osamu Fujimura, University of Tokyo; Dr. Manfred Schroeder, Bell Telephone Laboratories, Murray Hill; and Prof. Kenneth Stevens, Massachusetts Institute of Technology, Cambridge. The title of their panel discussion was "Tomorrow's Research in Speech."

Although the bulk of the 75 technical papers[2] presented dealt with specific research on well-defined questions of speech synthesis and analysis, automatic recognition, and speech compression, the panel participants were asked to stand back to look at the complete picture. The discussion turned out to be primarily a "working" session—experts talking together and setting the research pace—in contrast to the panel a year ago when the experts were talking to nonexperts in the hope of arousing a wider interest in speech problems.

The Cambridge panel was, in fact, governed by a different set of questions: What are today's crucial research issues? How should current research on these questions be assessed? And, particularly, what direction should speech research now take? The discussions revealed that there has been a marked shift of emphasis in speech research. Whereas substantial research applied to the acoustical and production levels of speech has given investigators a footing in these areas, the territory of speech perception is still uncharted. What is now needed, it is said, is the same kind of penetrating research on human speech perception to put it on a footing comparable with the other areas of speech research.

The questions put to the panelists were interpreted pragmatically in their formal statements. For instance, in his opening remarks, Dr. Cooper said: "A listing of all possible paths to the future is hardly what we want. I believe we should put our money down on one or two paths, say where we think they will lead us, and why they may be important."

Following are excerpts from the formal statements of the panelists.

F. S. Cooper on types of models

My first choice is not a new one, but I do believe in its importance. It is an increasing emphasis on trying to understand the nature of the speech process. The tangible result would be better models of the process, and these would find application in various engineering developments and in education.

But, in thinking about models, one has to bear in mind that there are several kinds. One is an oversimplified idealization designed primarily for convenience in computation—and very useful for that purpose so long as it bears some resemblance to reality. At the opposite extreme is the model that insists on total realism and, in so insisting, gives up so much simplicity that it ceases to be very useful. It is the in-between kind of model we must seek. Such a model identifies the independent variables—that is, it matches reality one for one—and yet retains simplicity. Now, where do we find such models for the speech process? What kinds of research will suggest models that combine simplicity and predictive power?

One possibility is to look at the articulatory process itself, and to look as far upstream toward the message source as our research tools will allow. We can bypass the acoustic output, and even the articulatory shapes as revealed by X-ray movies, to concentrate on the neural signals and muscle contractions that make the articulators move. In this kind of research, one relies for guidance on a motor model of the speech process.* Such a model can be satisfyingly simple; whether it will fully satisfy the data remains to be seen.

Another line of research with implications for model building is the study of laterality effects, i.e., what happens when you listen to competing messages that enter the two ears simultaneously. The right ear has the better path to the left hemisphere, where speech processing is usually done; hence we can examine, without opening the skull, how the perceptual processing of speech (put in via the right ear) differs from that of other, nonspeech sounds (via the left ear). There are very real differences, which tells us again that speech is a special process and that we will not understand it so long as we think of it in the usual psychoacoustic terms. To be sure, speech shares properties with other sounds, but it also has special properties of its own—and will need its own model.

Suppose such a model existed. What consequences would it have, say, in engineering? One example on everybody's mind these days is speech recognition and, through it, the ultimate in bandwidth reduction. We are not likely to make good progress toward either of these until we have a deeper understanding of the characteristics of the human speech process. Otherwise, there are too many possible approaches. For the present, we think we are doing rather well when we score in the high 90s on automatic recognition of vowels, or of selected words, but this is a very long way from connected speech spoken in a conversational way. That is what we must shoot for, but it is unlikely that we will find a purely engineering solution to speech recognition—or any other solution that deviates significantly from man's natural process.

We do know a little about the human processes of production and perception at the phonological level. The fact that we can speak and listen so fast (the rates are truly phenomenal when you compare speech with other acoustic signals) suggests that the serial stream of linguistic units comprising the message gets encoded somehow into a parallel set of features for transmission and then is recoded back into something serial. This serial string is then used in accessing a very large memory to recover the original message. If you want an idea of the magnitude of the access problem, put your finger at random into a collegiate dictionary with its vocabulary of 50 000 words or so. The chances are that the word you select will be familiar to you, and would have been if someone had spoken it. How do we get to the answer so fast from a string of features or phonemes? This is a problem in speech research that has hardly been touched as yet. And there are related problems of the same kind at syntactic and semantic levels.

I thus nominate intensive study of the nature of the speech process as a future direction for speech research. With a better understanding of the human process, we can build better models—and better machines, as well.

*Any adequate model must deal with both the perception and the production of speech, since they are intimately interrelated as earlier work on the acoustic cues has so strongly suggested. For a discussion of the interrelationships, an account of relevant experiments, and references to related papers, see Ref. 3.

G. Fant on modeling the auditory system

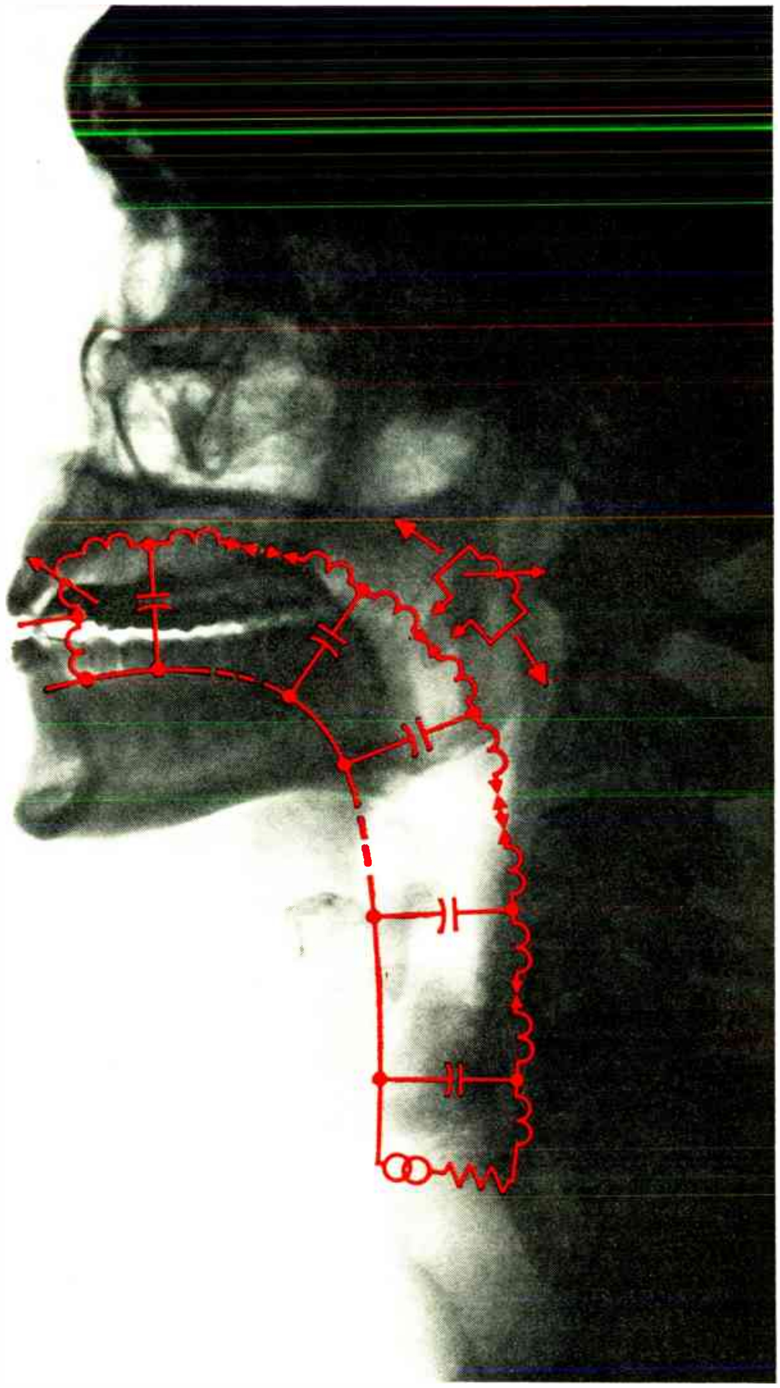
The field of speech research is still very young and we have far to go. I certainly agree with Franklin Cooper that our basic problem now is to learn more about the human factors involved. We want to know about the production level, the acoustic level, and the perception level.[4] What we can do in the applied fields is never better than our models.

There is one field whose direction we might fruitfully consider, which is in a sense applied, but which also belongs to basic research. This concerns the search for the principles involved in developing speech in the deaf and the hard of hearing. We need to study the processes involved to see how we can develop speech feedback mechanisms internally via kinesthetic and proprioceptive channels and externally via auditory, visual and tactile recording. Thus, we need further studies of the neurological levels of speech production and control. One motive for recent research on speech production is that if we have access to the organizing principles of production, then we can predict the variability of the speech wave. The acoustic speech wave itself has been found to be so difficult and messy to deal with that investigators felt obliged to turn to the production end in the hope of finding simplicities and invariants there that were not evident on the acoustic level. However, studies of mechanical and electrical activities (EMG) in articulators (lips, jaw, etc.), though useful, do not reveal invariant sets of signals. Discrete units such as phonemes and distinctive features† may belong to a higher brain level. If we wish to study perception on a broader basis, there is very much to be done. We must attempt to develop an integrated view as to how the distinctive features of speech are evaluated in the human auditory system as a function of the composition of the complex speech stimulus. This means looking at the relative role of feature cues, how perception integrates over successive wave segments, and the conditioning effect of the immediate phonetic frame.

A. Fourcin on matching machines and men

Apart from the results we may obtain from a dynamic, three-dimensional study of vocal cord movements, possibly through ultrasonics or associated techniques, I believe that work on the acoustic level of speech production is going to diminish. The emphasis is almost bound to be, in the next decade if not earlier, centered in several areas of pure research; on a newer mapping of cortical

† The term "distinctive features" refers to an approach to the analysis of the structure of linguistic signal put forward in 1952 by Jakobson, Fant, and Halle. The features are the ultimate discrete oppositions by which linguistic signals are distinguished from one another. Any language code has a finite set of distinctive features and a finite set of rules for specifying the combinations of features and the sequences of such combinations that are permitted in the language.



THIS X RAY of a man's vocal tract is superimposed with the schematic of an electrical vocal tract invented by H. K. Dunn in 1950. Dunn's model was the first step in the direction of representing the distributed nature of the vocal tract. Dunn treated the vocal tract as a series of cylindrical sections, or acoustic lines, so that it was possible for him to use transmission line theory in finding the resonances. This early electrical model produced acceptable vowel sounds and was used in research on the phonetic effects of articulator movements. As simple as it was, the model pointed a way for much subsequent research, and it has been greatly elaborated since. A large number of sophisticated speech synthesizers were demonstrated and discussed at the Cambridge speech conference. The subject of this X ray, by the way, is Dr. J. L. Flanagan, chairman of the panel discussion reported in this article.

control; and on the study of the mechanisms of perception.

Our past solutions to practical problems in the speech area have been based on theoretical approaches that are only rough approximations. We've got to find out much more about how human beings those who are to be served by the speech machines—really function, and then make the machines work in the same way. In fact, future applications, as well as problems, will depend on getting a much better match between machinery and speakers and listeners. Speech devices will have their forms and functions determined more by basic human activities than by an imitation of the latest engineering techniques. To solve the problems of speech recognition, as both Cooper and Fant have said, we must learn more about the processes of human speech perception. Speech problems in the future are going to be problems much more of theory than of technique.

O. Fujimura on the need for a probabilistic model

I would like to emphasize that the science of speech or language is an experimental science in the sense that experimental support is needed to establish the validity of a hypothetical model. Speech is such a complex and variable phenomenon that we need to postulate a well-formulated model to account for the facts rather than to describe the facts and reorganize data accordingly.

I think the situation is complicated in part by the fact that a listener can operate in many different modes of speech perception, giving rise to an apparent variability of human response to a given verbal signal. For example, an ordinary conversation may not put the speaker in the same perceptual mode that is in operation for listening tests of, say, consonant–vowel syllables. The phonological mode of identification, which might be in operation in the latter case, may be used typically in a situation in which the listener tries to identify an unknown name.

We will not be able to account fully for human speech behavior without considering the syntactic structure of language. Recent progress in theoretical linguistics must be appreciated and taken into consideration for speech research; and we must contribute to this branch of science by providing experimental support for the theory. However, we have not yet solved the problem of the syntactic surface structures (and hence the phonetic structures) of languages. Until this problem is solved, linguistics will suffer from a lack of evidence for the theory of grammar, and speech science will be held back from fundamental advances.

Consideration of the syntactic structures of the language in use, however, is not sufficient for explicating verbal behavior. In particular, if we would like to simulate speech phenomena quantitatively, it will be necessary to introduce a probabilistic point of view. This may be thought of as a semantic approach. Processes of a statistical nature can be considered practically only in terms of the deep structure of language. In a normal conversational mode, the probabilistic process is organized so that a listener (or even a speaker in a sense) predicts the probable "contents" of the incoming message and derives signal forms to be matched with the received signal. The content at the underlying level is represented by grammatical forms that interrelate particular elementary (lexical) items. In order to excite particular items in particular grammatical relations, we need to postulate a probabilistic association procedure. The point is that such association will not necessarily occur at the surface level. This makes machine simulation of such procedures rather complex and extremely difficult.

M. R. Schroeder on the history of speech research

This meeting occurs at a turning point in the history of speech research. For the past several decades, and in fact until a few years ago, the dominating incentive of much on going speech research was to find ways of more economic speech transmission. Today, our main interest in applications has shifted to speech synthesis by rule, automatic speech recognition, automatic speaker verification, and other requirements of facilitating man–machine dialogue. Concurrent with this new emphasis has come a growing appreciation of the importance of fundamental research in speech production and speech reception.

Another factor contributing to this evolution is the increasing availability of new tools. Foremost among these are digital computers used for simulation of models and on-line experimentation in speech perception. The impetus of computer-controlled graphical displays in speech research is just beginning to be apparent. New measurement methods have been introduced to complement established experimental tools, such as X rays, high-speed photography, and electromyography. Among these new tools are acoustic impedance measurements to determine vocal tract area functions and ultrasonic probing to measure movements of vocal organs. Before long, we may be mapping articulator positions in three dimensions using acoustical holography or other imaging methods based on sound waves. Image reconstruction can be done on computers with three-dimensional graphical display.

In addition to these physical tools, new methods for multidimensional scaling have become available that could be exceedingly fruitful in furthering our understanding of speech reception, an area second to none in importance, yet one in which our knowledge is still fragmentary. Another recent analytical tool, which is still being perfected and has yet to be applied, is that of finding transformations that will make complex data depend in a simple, additive way on a small number of parameters. If speech can indeed be considered as resulting from a discrete sequence of neural commands then these new mathematical algorithms will help us to either establish this fact or suggest more productive directions.

Much of what we have done in speech in the past has resulted directly or indirectly from the dream of Homer Dudley back in the 1920s. He wanted to transmit speech over a new transatlantic telegraph cable that had a bandwidth of a little more than 100 Hz. Today, almost 40 years later, that dream of using vocoders for intercontinental communication has been realized, but not on a large scale. The reason is that, thanks to transistorized telephone cables and communication satellites, we have been so "swamped" by undreamed-of bandwidth that the vocoder, in some respects, seems destined for the museum.

But in the process of trying to decode and reduce speech to its basic elements for narrow-bandwidth transmission, we have learned a great deal about speech and many useful and sometimes unexpected applications have appeared. Rate-controlled speech (accelerated or slowed down) are among such applications; the reconstitution of "helium speech" from deep-sea divers is another. Speech privacy is of increasing concern; in this respect, speech processing by vocoder could allow the transmission of encrypted speech over ordinary telephone circuits. Audio-response units using stored vocoder signals are finding increasing attention. Earlier speech research has already led to many aids for the handicapped. Accelerated speech benefits the blind, and slowed-down speech may help the mentally retarded. Tactile vocoders continue to be explored for the deaf. Compression of high-frequency components and transposition to lower portions of the spectrum may be useful for the partially deaf. Artificial larynxes have been commercially available for some time. All this makes one feel hopeful that present and future speech research will likewise result in many worthwhile applications. There has already appeared on the horizon a method for portraying articulator motion, a "visible articulation," derived directly from the speech signal; it might be useful in research on speech recognition and automatic speaker verification and might serve, as well, as an aid for the deaf.

The possibilities for speech synthesis by rule, automatic speech recognition, and automatic speaker verification are immense. But will we achieve these goals or will we see all kinds of other, unexpected, applications and be reduced in our dialogue with computers and automata to graphical and other nonacoustic modes? This will depend largely on the progress we make (or do not make) in the next five or ten years. What will be the test of our success? Will synthetic speech be used widely or will it remain a curiosity? The answer to this question will be the true test of our level of understanding of speech production and particularly of speech perception.

K. N. Stevens on the study of context

I agree with Gunnar Fant that speech research is still in its infancy, comparable to the state of chemistry before the periodic table. Chemists could make many experiments, but were unable to organize their findings into a clear theoretical framework. Our problem is that we don't know yet in detail the nature of the code fundamental to speech production and perception.

In our research on the nature of distinctive features and phonetic units, we must recognize that such features of speech are not arbitrary or mysterious codes for transmitting linguistic information; these codes are biologically determined. We happen to use these particular codes because we are built in a certain way, because the mechanisms of hearing and of speech generation have special attributes. At present, our understanding of these mechanisms is fragmentary, and we can state only in broad terms the acoustic, perceptual, and articulatory correlates of the features.

Those who work on speech should keep in mind all of the different levels—acoustic, perceptual, and production—because the features, it seems to me, are tied to all of these levels. There is a common code, as I have noted, and we must determine the inventory of features and their correlates before we can proceed very far.

We do have, as Manfred Schroeder said, many new experimental tools that can help us very much in our research. We should be making use of these not only to build better speech recognizers and speech compression systems, but to study the basic nature of speech as well. We are beyond the point where we need to rely only on visible speech patterns to study the acoustic properties of speech; we can use computers in many ways to display and to study acoustic characteristics.

Those who work on the electrophysiology of hearing are still at a stage where they are utilizing rather simple signals, such as tones and clicks, to investigate how the auditory system works. I should think that within the next five years their knowledge of the auditory mechanism will have developed to the point where they will be ready to use more complex stimuli that are more speech like. Thus they will be able to gain an understanding of how the auditory mechanism responds to speech and, hopefully, find a physiological basis for language features.

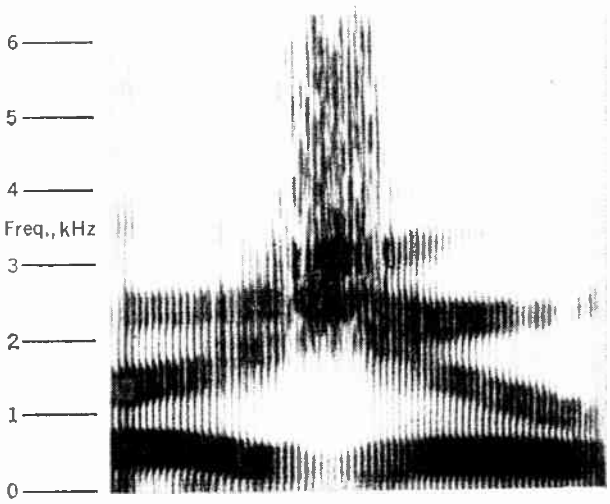
On the other hand, when people try to develop procedures for automatic speech recognition, it is quite clear that ideal acoustic correlates of the features do not often appear as they should. Thus, in our studies of the nature of the consonant in a consonant-vowel syllable, for instance, we are studying a "frictionless" or idealized case. We must include in our investigations how the features are modified or distorted when they occur in rapid speech and in various kinds of contexts. Studies of the dynamics of articulation will help us in this research.

Likewise, to understand the perception of speech, we certainly need to determine how we, as listeners, utilize higher-level linguistic information. How do we make use of the lexicon that is presumably stored in our memory? How do we make use of phonological rules? It is clear in conversational speech that the acoustic signal alone does not carry all the information. As we listen to such "incomplete" speech, we probably fill in the missing information from our knowledge of the context. An important goal of speech investigators is to learn how we are able to do this filling in through the use of contextual, semantic, and other information.

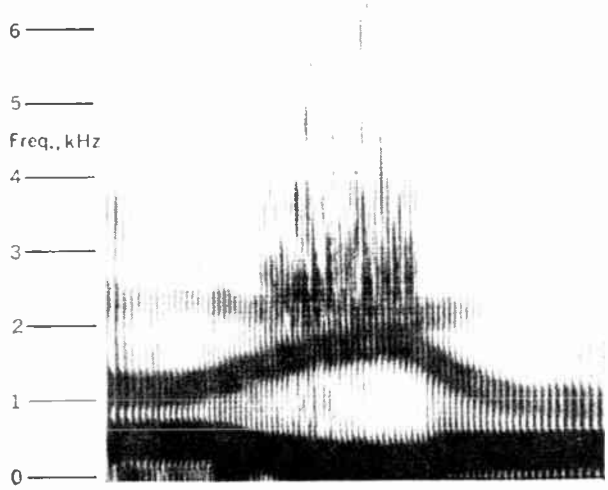
On the question of invariants in speech

In the discussion following their formal statements, the panelists went further into the problems of detecting features of speech owing to the extreme variations between speakers, the influence of different phonetic contexts, etc. K. N. Stevens made the point that, despite the bewildering variations evident in speech behavior,

SPECTROGRAMS of real and synthetic speech for syllables. The synthetic speech was generated from the synthesis-by-rule method described by L. R. Rabiner at the conference. Aim of synthesis is natural-sounding speech.



əʒu (human speech)



əʒu (synthetic speech)

speech investigators should not abandon the search for acoustic invariants; instead, he said, with the new techniques becoming available for looking at the acoustic signal, the investigators should be "looking harder."

The discussion then led to an interesting proposal by J. L. Flanagan that in itself also seems to define the forward frontier of the perception problem. "We know," he said, "that trying to learn how the auditory system processes speech signals is a very complex problem. Only now are we having some success in correlating subjective response to simple signals, as measured in psychoacoustic experiments, and the electrophysiological response of the auditory system to these same signals. So far these signals have been chosen to be analytically tractable, usually temporally punctuate or spectrally discrete. For example, it is relatively easy in a psychophysics experiment to require a person to, say, make a pitch match between two periodic signals—that is, to equate the two signals in subjective frequency. We can then go to physiological data measured for the same signals and, with our present understanding of the auditory system, interpret the subjective behavior in terms of what we see in neural histograms or in terms of inner ear motion. If we are to make the same kind of correlation for speech signals, we've got to have suitable means for characterizing subjective response to speech signals. That is, we need subjective measures of speech perception that we can relate to what we see neurophysiologically. The question is, how can we design speech perception experiments that will help us bring together, on the one hand, the subjective behavior, and on the other, what we hope eventually to be able to see in the physiology, particularly in the neural physiology of the auditory system?"

In responding to this suggestion, Cooper noted the depth of the challenge by comparing it with work in the past on the phoneme level. "The small successes we have had," he said, "are due largely to the fact that linguists have given us a principle and a tool; thus, they tell us that language is a categorizing process and they have identified the phoneme categories. Knowing this, we can start with a great mass of amorphous sonic substance and eventually write it down as a string of 'letters'; that is, there is a reduction of what was amorphous to a set of accepted categories. When you ask about the nature of speech perception in general, the problem is much harder because we do not have an adequate set of categories." What is needed, evidently, is a specification of linguistic constraints in the characterization of the subjective responses.

Schroeder, too, assesses the electrophysiology of speech signals as being still rather far in the future. He notes that investigators have studied some physiological events connected with such simple phenomena as speech frequency shifts but that for more complex speech events the way is still dark.

On practical automatic speech recognizers

In a kind of momentary retreat from such complex problems, the discussants took up the question of the possibility of practical and useful speech recognizers that do not overtly attempt to duplicate the details of human perception. As Flanagan put it, such recognizers would do a reasonably satisfactory job, for a limited vocabulary, and for a very narrowly defined purpose.

Fant responded that for such simple cases, in which the context is well established, only a small fraction of the information in the speech wave would be required, and it would not be necessary to look into anything as sophisticated as the human perception of speech. "I think it is quite obvious," he said, "that if you work with a limited inventory of speech sounds, the linguistic and contextual constraints are so powerful that you need only very primitive acoustic measures to ensure an acceptable level of performance."

During the discussions, a number of examples of automatic speech recognition system applications in which the vocabulary is highly constrained were put forward. It was suggested that there may well be unexplored situations in which rudimentary automatic recognizers could profitably be used.

Fujimura followed up these ideas by noting that there are many kinds of approaches to perception and that there could be various kinds of machine approximations to the models of speech perception. "Even the human being," he said, "does in a particular situation something quite different from what he could do in *any* situation. This is a difficulty for a machine. We may make a machine that would behave just like a human being in a particular situation, but a human being can change his response and put himself in a different mode. This is a very easy act for him, but not for a machine. Very probably, if we can specify in which situation or in which mode the machine should work, then probably we can make a practical automatic recognition system."

This question on the variability and complexity of speech, on how the features are modified in various contexts and on the need for a probablistic model cited by Fujimura earlier, once again carried the discussion into murkier areas.

Cooper then postulated another possibility of future research. "We have tended thus far in speech research," he said, "to say that speech is something that comes in a standard-size package, labeled *Made by Homo Sapiens*; further, we have assumed that it was our problem to deal with this standard item. Now, speech is almost certainly nonstandardized. We all know this, and yet I'm not sure we all act as if we did.

"Individuals can certainly do very different things with their mouths, and still make more or less similar acoustic waves, or at least acoustic waves that are accepted as exactly alike in terms of the message they carry. People do not have to make the same oral gestures; if they generate the coin of the realm in the acoustic domain, they can do it any way they wish. I think we will find, particularly in the physiological area, that individual differences are very large, and they may be very revealing—particularly when one is considering speaker identification. But, even in dealing with the acoustic cues for speech perception, we may find more variability of a *nonstatistical* kind than we have thus far taken into account."

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Utility system effects of space plasmas

Enigmatic, strange effects have been produced by solar flares and their ensuing phenomena. It is the author's premise that these occurrences dramatically affect the performance of many power and communications systems

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Space plasmas and their unpredictable effects are objects of intensive study by NASA, the armed services, and participants in the International Geophysical Year investigations. There seems to be a direct correlation between solar hyperactivity and geomagnetic, as well as magnetotelluric, field fluctuations. Cosmic rays increase in intensity; and radio communications suffer. Various agencies are predicting an unusual increase in solar activity by the end of this year. What, if any, will be the observable result?

Solar activity can be expected to peak near the end of 1968 with the approach to another International Geophysical Year (IGY). During this period, the nature of solar flares, the travel through space of their plasma or ionized gases, and their arrival and influence on earth will receive considerable attention. Based on previous records,[1–4] some utility systems will experience real and reactive voltage variations; transformers, underground cables, pipelines, grounded devices, and systems will experience large current flows; and earth environmental fields will undergo large amplitude and erratic frequency changes—all at the same time—as earth effects of solar activity.

Increased solar activity

The 1966 article on "Plasmas in Space"[5] in IEEE SPECTRUM describes the space physics involved in this phenomenon, and points to an increased number of sunspots that occur within an approximate period of 11 years. The maximum number of sunspots should occur about mid-1968 to mid-1969; however, scientific study predicts that they can also be expected to increase in number during other periods. If they have increased in number, as expected, about February 9, 1968, predicted solar flare and proton storm will have occurred, since the number of sunspots and the probability of a flare occurrence are directly related. During such activity, cosmic rays with energies of 100 MeV have been measured. Also, protons with quiet-sun densities of about $5 \times 10^6/m^3$ increase greatly in number. The protons travel at a radial velocity from the sun at a rate of about 335 km/s, and their arrival at earth causes magnetic storms. These influence both geomagnetic and earth-current fields (magnetotelluric fields),[6] which are time-related to utility system effects. All of these provide considerable data on ionospheric disturbances and environmental effects as shown by Fig. 1.

Consider the effects of one such flare that occurred near the earth side of the sun on November 12, 1960, at about 1323 Ultimate Time (7:23 A.M. CST). This began as a brilliant explosion on the face of the sun that sent out a gigantic cloud of solar gases, traveling by way of the solar wind to the earth. Dorothy Trotter, of the National Center for Atmospheric Research High Altitude Observatory at Boulder, Colo., provided this report[7] on the occurrence of the flare:

"Region 60HH produced a number of major flares that resulted in severe disruption of short-wave radio communications; and a bright aurora was visible in the United States. But this region's greatest distinction came more than a day after it had rotated onto its invisible disk, when it produced a tremendous flare, with a resultant cosmic shower. From the 10th through the 15th of November (1960), major flares occurred, associated in time with major bursts somewhere in the range of 55–9800 MHz. Fast-drift bursts in the decameter range were fairly common, and some cases of slow-drift bursts and continuum were observed. Short-wave radio was severely hampered on numerous occasions during the passage of this region. The region produced a class 3 flare (on a scale of 0–1 min. and 3 max.) at 1009 Ultimate Time (UT) on November 10th; a 3+ about 1323 UT on November 12th; and another 3+ at 0207 UT on November 15th. Sudden com-

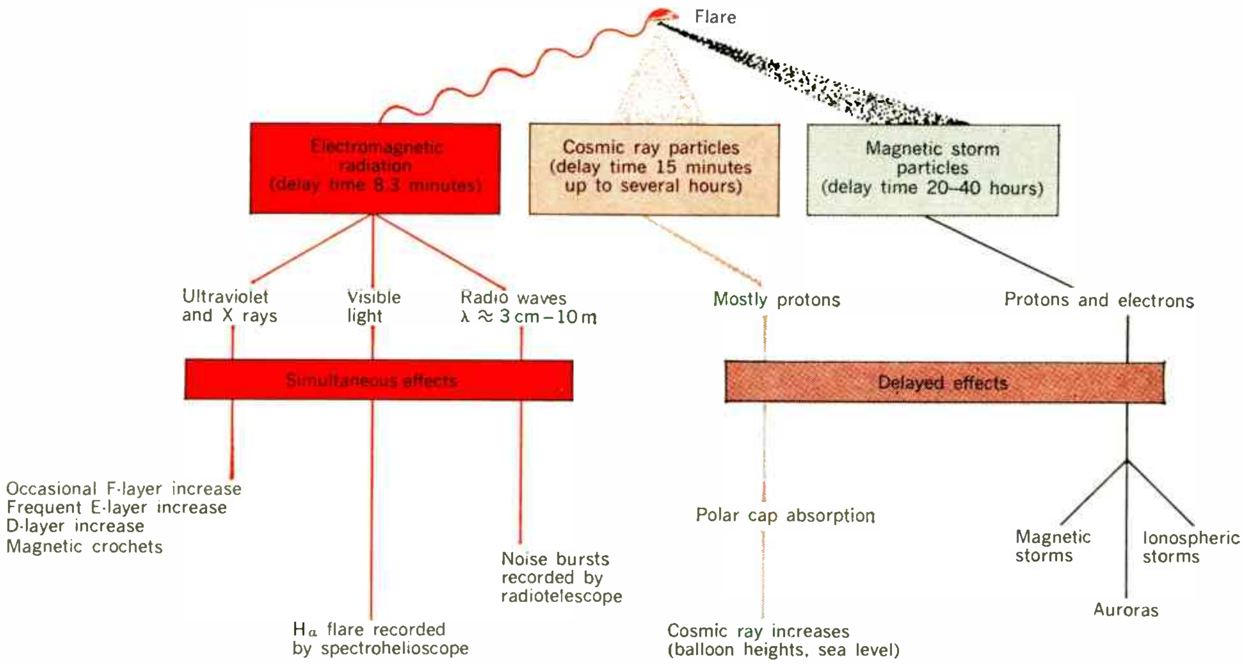


FIGURE 1 (above). Terrestrial effects of a solar flare. (Courtesy National Bureau of Standards)

FIGURE 2 (right). Chart showing maximum voltage variation at Little Falls, Minn., hydroelectric station on Nov. 13, 1960. (Courtesy Minnesota Power & Light Co.)

mencement of storms began at 0034 UT on November 11th; 1349 UT on November 12th; and another at 1304 UT on November 15th. We feel that these storms were the direct result of the energy emitted by these flares, even though the elapsed times of 14 hours, 24 hours, and 11 hours, respectively, are uncommonly short. The flare on the 12th of November was distinguished also by an associated 'great burst' recorded in Ottawa at 2800 MHz."

Effect on VLF communications

According to a report on "Propagation of VLF Waves Under Disturbed Conditions," by Burgess[8]: "During November 1960 the anomalous very-low-frequency phase variations underwent daily changes some five to ten times greater than normal. The phase records had already begun some 20 hours after the associated flare of November 12th, and continued for at least nine days."

From magnetograms and hourly values recorded at Fredericksburg, Va., the declination of the earth's geomagnetic field showed maximum changes for average hourly values of 6° West declination between the hours of 2 A.M. and 6 A.M. (EST), Nov. 13, 1960.

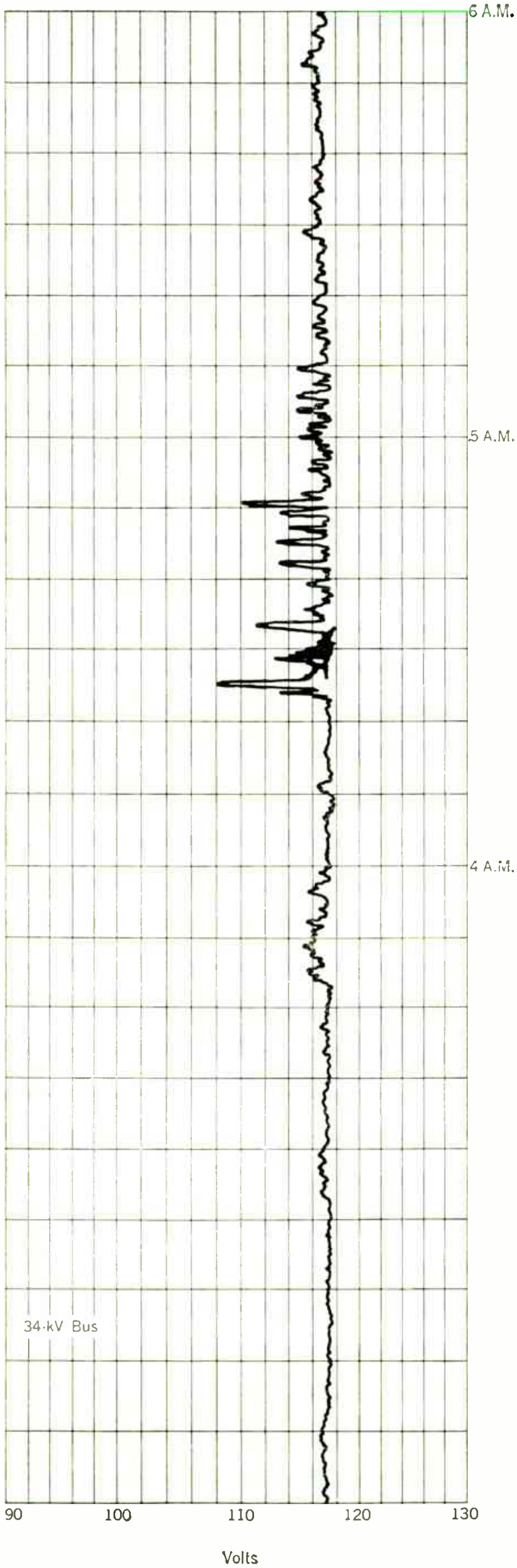
For the same period, information was received from Roy Ohman, manager of operations, Minnesota Power and Light Company, Duluth, Minn., as follows:

"I have several charts showing the disturbance on our system Sunday, November 13, 1960, between the hours of midnight and about 7 A.M. The maximum voltage excursion (Fig. 2) occurred at about 4:25 A.M. at our Little Falls, Minn., hydro station. Voltage there varied from about 117 volts to about 108 volts for several minutes. The Riverton Station near Brainerd, Minn., varied by about 5 volts. Reactive power from our Clay Boswell S.E. Station varied from 34 to 63 Mvar, all at the same time."

Power fluctuations

It has been well recorded[9] that earth currents increase in magnitude, and voltage variations become quite large, during magnetic storms.[10] Therefore, it may be assumed that such large power fluctuations did occur. Such currents are easily large enough to create the overheating and corrosion that appear as effects in the high-conductivity, northern-latitude areas. Although conductor vibration has generally been considered to be basically a wind-induced problem, investigation[11] shows it to be a more complex phenomenon. Environmental conditions—wind, ionized air, magnetotelluric-field activity—and system voltage, position, and the conductors' mechanical characteristics are interrelated as to their effects, and the effects on them of solar plasma. All of these determine vibration amplitude, frequency, area, and time of occurrence. Vibration is a more severe problem in areas with high ionization. These areas, in turn, are related to high-conductivity areas; and vibration increases with ionization level gain from space plasma. This effect was noted by Myron Broschut of Otter Tail Power Company on their line near Fargo, N.Dak., during the November 12, 1960, storm. Long duration and high amplitude of vibration clearly mark the arrival of the storm on the charts. Judging from other data on this and other utility system lines, conductor vibration has a frequency-range power spectrum that is very similar to those values recorded for the earth's natural electric field by comparison of charted data. These extra-low frequencies of the earth's field are shown in Fig. 3.

With the increase in system voltages and the increasing importance of system stability, the nature of space plasmas and their effects on utility systems present a most important study for future utility system design. However, as



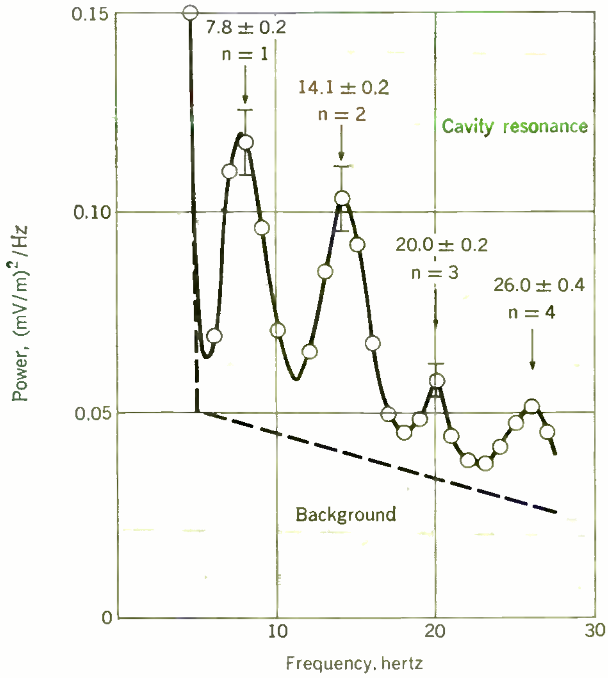


FIGURE 3. Mean ELF spectrum of the natural vertical electric field observed in 1962 and 1963. (Courtesy National Bureau of Standards)

a result of our increased scientific knowledge from space probes, solar system studies that provide both long-time[12] and short-time warning of solar flare activity, and utility system research directed toward time, position, and magnitude of plasma effects, our engineering progress will bring greater understanding of these utility system phenomena.

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Computer science in electrical engineering

The computer revolution has made a significant impact on electrical engineering curricula. The electrical engineering department's new role and the need for greater course flexibility in the computer environment are examined

COSINE Committee
of the Commission on Engineering Education

The vital role that electrical engineering departments must play in providing undergraduates with special competence in computer sciences is explored. Three related problem areas are discussed: (1) meeting the needs of students majoring in computer sciences in electrical engineering; (2) balancing the treatment of continuous and discrete systems so that students have a background in discrete systems comparable to that which they now acquire in continuous systems; and (3) realizing wider and more effective use of the digital computer as a tool for analysis and design in all engineering courses. Specific suggestions for meeting these needs are offered.

The rapid growth in the accessibility and power of digital computers for purposes of numerical computation, data processing, and retrieval of information is having a deep, though not necessarily uniform, impact on all branches of science and engineering. Although most branches of science and engineering are concerned primarily with the *use* of digital computers, electrical engineering, by virtue of its long standing and deep involvement in information-processing technology, has vital concern not only with the use but, more important, with the conception, design, and construction of digital computers. Moreover, electrical engineering is deeply involved in a wide gamut of areas that border on or are contributory to computer technology, such as integrated circuits, switching theory, and finite-state, control, communication, and adaptive systems.

During the past several years, the rapid growth in the use of computers in science, engineering, and many other fields has tended to shift the emphasis in computer technology from circuit and component design to system organization and programming or, in roughly equivalent but more succinct terms, from hardware to software. This trend has given an impetus to the crystallization of what is now widely referred to as computer sciences – that is, an aggregation of subject areas centering on the use of computers as large-scale information-processing systems.

Clearly, it would be unreasonable to equate the computer sciences with electrical engineering, or to regard it as a subset of the latter. Nevertheless the close relation between the two is presenting electrical engineering departments with a special responsibility for the training of large numbers of computer engineers and scientists. This responsibility derives not only from the close connections between electrical engineering and computer technology, but also from the traditional emphasis in electrical engineering curricula on physical sciences pertinent to information processing; the extensive experience in teaching mathematically oriented subjects relating to signals and systems; the tradition of analyzing system behavior on an abstract level without regard to the physical identity of its variables; the existing expertise in subjects that fall into computer sciences or are closely related thereto; and the vast resources in facilities and faculty which the electrical engineering departments have at their disposal.

The emergence of computer sciences as a highly important field of study, coupled with the growing shift in emphasis in information-processing technology from the analog and the continuous to the digital and the discrete, is creating an urgent need for a major reorganization of electrical engineering curricula. Such a reorganization must, in the first place, accommodate the needs of students who wish to major in computer sciences within electrical engineering. Second, it must bring into balance the treatment of continuous and digital systems, and provide all electrical engineering students with a background in digital systems comparable to that which they currently acquire in continuous systems. Third, it must result in a much wider and more effective use of the digital computer as a tool for system analysis and design in all engineering courses.

The COSINE Committee feels strongly that, as an essential first step, electrical engineering curricula should be made substantially more flexible. The movement toward greater flexibility is already under way in most engineering curricula; it is only in the climate of flexibility that engineering education can respond to the rapid advances in science and technology and adapt to the explosive growth in knowledge that is now taking place.

Because it is one of the fastest changing fields in natural sciences, and owing to its wide diversity of subject areas, the need for flexibility is particularly acute in electrical engineering. Apart from computer sciences, the fields of solid-state electronics, quantum and optical electronics, integrated circuits, bioelectronics, plasmas, control, communication, and large-scale power systems are but the more prominent of the many important subject areas that comprise electrical engineering. Each of these areas has its own needs and objectives, which, in many cases, cannot be satisfactorily met within the framework of a single curriculum with just a few electives and a large core of required courses in engineering and electrical engineering.

A climate of flexibility is thus essential for the accommodation of the needs of computer sciences as well as other subject areas within electrical engineering. It should be noted that some electrical engineering curricula already offer the student almost a full year of electives with more available by route of petition. In most cases, this approach is sufficient to enable a student to focus his studies in a field of concentration that may be either computer sciences, or computer sciences in combination with such areas as circuits, systems, control, or solid-state devices. The committee feels that flexibility of this order of magnitude would permit many diverse educational programs to thrive within electrical engineering and make it possible for students in such programs to acquire excellent training in both the foundation subjects in electrical engineering and the more specialized subjects in their particular fields of interest. Indeed, such training would serve well not only the needs of those students who would continue their studies toward higher degrees, but also of those who would terminate their formal education at the undergraduate level.

A computer science program in electrical engineering

By a computer science program in electrical engineering the committee means a curriculum in electrical engineering education that allows the student to acquire substantive competence in computer sciences and related fields, comparable but not necessarily similar in content to that acquired by students in a typical computer science department. Such a program must fulfill the following aims:

1. It must provide the student with a thorough understanding of computer systems and their use that is based on fundamental principles of long-term value rather than the salient facts of contemporary practice.

2. It must give the student a background in relevant discrete mathematics (set theory, mathematical logic, and algebra) including familiarity with methods of deduction as applied to abstract models relevant to the field of computation.

3. It must give the student access to a variety of subjects covering specialized and advanced aspects of computer science.

4. It must provide the student with sufficient technical and general knowledge that he can readily broaden his

This article is a condensation of a report, of the same title, issued by The Committee on Computer Sciences in Electrical Engineering (COSINE Committee) of the Commission on Engineering Education. Chaired by Dr. Samuel Seely, educational consultant, the committee includes J. B. Dennis (M.I.T.), D. C. Evans (University of Utah), W. H. Huggins (Johns Hopkins University), M. Karnaugh (IBM Corp.), J. F. Kaiser (Bell Telephone Labs.), F. F. Kuo (University of Hawaii), E. J. McCluskey (Stanford University), W. H. Surber and M. E. Van Valkenburg (Princeton University), and L. A. Zadeh (University of California). Copies of the report may be obtained by writing to the Commission on Engineering Education, Washington, D.C. 20036.

education through continuing study and remain adaptable to the changing demands of society throughout his professional life.

Our discussion relates to the first three of these objectives; achieving the last objective is left to the discretion of each university.

The committee recognizes the inherent difficulty in attempting to specify a detailed curriculum in computer science; no single curriculum could possibly fit into the variety of programs and organizational frameworks present in electrical engineering departments. We have, therefore, organized the material into *subject areas* as shown in Table I; each subject area is a collection of related topics having cohesion and purpose. In describing a subject area, the committee does not wish to imply that it necessarily corresponds to a single one-semester course. Furthermore, the description provided for each subject area is intended only to indicate what the committee regards as a reasonable set of topics and their logical order, without implying that strict adherence to the description is expected.

Category A comprises four subject areas that the committee feels are of central importance and basic to an adequate education in computer science. Other subject areas, which are less central but which nonetheless cover important related and specialized material, are listed in Category B. The committee feels that these subject areas should be available to students in the computer science program. However, we do not view Category B as necessarily complete, since there are legitimate differences of opinion on whether additional areas should be offered.

A computer science program in electrical engineering can assume a variety of forms. It can start at the freshman, the sophomore, or the junior level. It can be structured as an option with specified required courses, restricted electives, and unrestricted electives. It can be realized by allowing for enough electives in a standard electrical engineering curriculum to make it possible for a student (with the help of a faculty advisor) to put together a program of his own in computer sciences. It may or may not include a core of required electrical engineering courses in areas outside of the computer sciences. Accordingly, the subject outlines presented here should be regarded as guidelines intended to assist electrical engineering departments in devising curricula in computer sciences.

Finally, the committee takes no position on jurisdictional questions relating to departmental responsibility for particular courses. Because information processing in all of its forms will continue to be of major concern to electrical engineering departments, the committee feels that electrical engineering faculties should strive to develop strong expertise in computer sciences and related areas. At the same time, it is essential that electrical engineering departments cooperate closely with all departments having interests in computer sciences, sharing with them the responsibility for providing instruction in computer-oriented courses and for conducting research in computers and computer-related areas.

I. Subject areas for a computer science program in electrical engineering

Category A: Basic subject areas
- Programming principles
- Computation structures
- Introduction to discrete mathematics
- Machines, languages, and algorithms

Category B: Recommended elective subject areas
- Digital devices and circuits
- Switching theory and logical design
- Programming systems
- Operating systems
- Numerical methods
- Optimization techniques
- Circuit and system theory
- Information theory and coding
- Functional analysis
- Combinatorics and applications
- Probability and statistics
- Symbol manipulation and heuristic programming

Category A: Basic subject areas

We suppose that the student embarking on this program has had previous exposure to the use of automatic computing, whether in high school or in work experience. In some schools it might be desirable for students in computer science to take immediately the basic course: Programming Principles. In such cases, some arrangement to provide an early introduction to elementary numerical methods should be provided.

The four subject areas of Category A comprise material that is essential background for all students of computer science. Two subject areas, Programming Principles and Computation Structures, are intended to give students fundamental knowledge of the operation of general-purpose-computer systems and the important features of programming languages, with emphasis on computer hardware as the means of realizing programming features. The indicated sequence of development shows our preference for developing familiarity with programming features prior to the discussion of issues of machine organization, instruction, code design, and addressing mechanisms. In this manner, it is possible to motivate aspects of machine organization by the language features they serve to implement. This approach also places conventional machine organization in a less sacred light and should lead students to consider and evaluate alternative implementations.

The subject area labeled Introduction to Discrete Mathematics is intended to familiarize the student with mathematical concepts and techniques that are basic to the study of discrete systems. Such familiarity is essential for computer science majors, and certainly very desirable for all electrical engineering students.

The subject Machines, Languages, and Algorithms serves to introduce students to abstract formulations of certain important and related areas of knowledge concerning computation. These areas are not only important in their own right, but they give the student the background and experience that will enable him to make significant use of abstract modeling in his future professional work. Suggested content for these courses is considered in the following discussion.

Programming principles. A reasonable selection of topics might include practice in algorithm design and programming to provide familiarity with the primitive operations on commonly encountered data types—for example, truth values, integers, real numbers, arrays, symbol strings, queues, stacks, trees, and lists; infix

and polish notation for expressions and the use of a pushdown list for their intertranslation and evaluation; assignment operator, conditional expressions, iteration, and subscripting; programs as defining functions with certain domains and ranges; building complex programs (functions) through the composition (nesting) of more elementary routines: binding of arguments, local and global identifiers and their scopes, sharing, and recursion.

A formalism for defining the syntax of programming languages, such as the Backus–Naur Form (BNF), should be introduced and the notions of derivation and ambiguity treated.

Computation structures. A knowledge of logical design fundamentals is an essential component of this subject. Topics include the realization of Boolean functions by combinational gate logic, the flip-flop, registers as ordered sets of flip-flops, register transfer operations, and theory and design of sequential control logic. Basic topics on number representation and the implementation of arithmetic operations include the binary number system, representation of negative numbers, simple mechanizations of addition, multiplication, division, and floating-point representations of real numbers.

Introduction to discrete mathematics. A representative set of topics includes propositional logic, Boolean algebra, set-theoretic notation, axiom systems and formal deduction, formal and informal proofs, proof by contradiction and finite induction, quantification and its use in formalizing propositions, and application to the study of formal properties of number systems, graphs, fields, groups and semigroups, and linear transformations.

Machines, languages, and algorithms. The following is a representative selection of topics: the finite-state model, state diagram and flow-table descriptions, equivalent states, equivalent machines, state reduction, finite-state languages, regular expressions and Kleene's theorem, limitations of finite-state automata, formal languages, grammars and derivations, context-free languages and their relation to pushdown storage automata, ambiguity and other properties, and sentence-parsing procedures. Computability topics include Turing machines, universal Turing machines, the existence of noncomputable functions, the "busy beaver" and halting problems, unsolvable problems of practical interest (for example, undecidable properties of context-free languages), the computability of recursive functions, Post systems, and Church's thesis.

Category B: Elective subject areas

As already noted, the subjects in Category B are less central to a computer science program than those in Category A. Moreover, the following lists are not necessarily complete, and individual ideas can be reflected in this group.

Short descriptions of the subjects are given in order to indicate the content and level of the material. The subjects included may denote courses, and, in a few cases, they can represent more than one course.

Digital devices and circuits. Modeling of nonlinear circuit elements; approximate analysis of quiescent and transient circuit behavior; use of time-domain circuit simulation; designing to specification with imperfect components; worst case and statistical approaches to circuit reliability. Applications to flip-flops, multivibrators, and networks of cascaded gate circuits; signal transmission methods; integrated-circuit technology. Physical phenomena usable to realize memory functions; ferromagnetics, cryogenics, electrostatics, photochromic materials, sound waves; address selection principles (coordinate and serial). High-current switches for inductive loads; sense amplifier design; techniques for improving signal-to-noise performance.

Switching theory and logical design. Combinatorial logical design, including the notion of prime implicants. Huffman theory of sequential machines, both synchronous and asynchronous. Hazards and their resolution. Interconnection of submachines to form larger units. Time-independent logical design. Identification and diagnosing experiments. Error detecting and correcting codes. Languages for specifying digital systems.

Programming systems. Formal methods of specifying language syntax and semantics. Syntactic structure, parsing methodology, diagnostics. Advanced study of programming features—for example, data structures, properties of data types, block procedures and the context of identifiers, parallelism and sharing of data, protection and process monitoring features. Implementation questions, including symbol table structure, code optimization, efficient subscripting, flow-of-control analysis and loop organization, flow-of-control and loop optimization, subroutine linking and parameter passing, syntax-directed compiling.

Operating systems. Functions of an operating system, such as controlling the use of computer system resources by programs submitted for execution by its users and insuring the integrity and security of information held on behalf of users. Topics suitable for in-depth study include the concept of process, the blocking and awakening of processes, the meaning of interrupts, interprocess communication, and process scheduling; the concept of address space, binding of procedures and data to address space and interprogram linking, motivation for location-independent addressing and techniques of implementation, shared information; storage management aspects, such as movement of information within a storage hierarchy, file backup, and issues of data integrity on restart. File access control and transfer of access privilege.

Numerical methods. Solution of systems of linear equations (matrix inversion, gauss elimination, determinants, etc.), numerical solution of nonlinear algebraic equations, roots of polynomials, interpolation techniques and curve fitting, numerical integration, solution of ordinary differential equations, solution of partial differential equations, and linear programming.

Optimization techniques. Solution of linear inequalities, linear programming algorithms, convex sets and convex functions, nonlinear programming, quadratic programming, dynamic programming, gradient techniques, maximum principle, Markoffian decision process, optimization under vector-valued criteria, and search strategies.

Circuit and system theory. Circuits as interconnections of basic elements, including such topics as passive and active circuits, characterization of circuits in the time and frequency domains, solutions of differential input–output relations. State-space formulation and representation by differential and difference equations. Basic properties of linear systems, time-varying systems, and nonlinear systems. Controllability, observability, and stability.

Information theory and coding. Quantitative definition and measurement of information, entropy of uncertainty, memoryless discrete channel, capacity of a memoryless channel, capacity theorems. Encoding and decoding of messages, parity check codes, convolutional encoders and decoders, sequential coding. Practical digital communication systems.

Functional analysis. Functions, functionals, and operators. Metric and topological spaces, linear spaces, Hilbert spaces. Linear functionals, differentiation of abstract functions, homogeneous forms, and polynomials. Stationary problems, fixed point theorems, gradient techniques. Quasi-linearization. Applications to problems in optimization and identification.

Combinatorics and applications. Enumeration techniques, including permutations and combinations, generating functions, recurrence relations, the principle of inclusion and exclusion, Polya's theory of counting. Theory of graphs, including planar graphs and duality. Network flow problems and elementary linear programming.

Probability and statistics. The concept of sample space and random variables, probability distributions on discrete sample spaces, dependent and independent random variables, conditional distributions, distributions on continuous sample spaces, parameters of probability distributions, normal distributions, stochastic processes. Markoff chains, waiting-line and servicing problems, estimation techniques, stochastic approximations, and decision rules.

Symbol manipulation and heuristic programming. Heuristic versus algorithmic methods, LISP and other relevant programming methods, game-playing programs, question–answer programs, symbolic integration and differentiation, theorem proving, search techniques, simulation of learning and concept formation, applications to pattern recognition and information retrieval.

Table II places the foregoing discussion into the context of a four-year undergraduate program. This table contains only the basic courses in Category A plus an introductory course in Programming and Numerical Methods. Detailed curricula of two electrical engineering departments, which show how they have included a concentration in computer sciences, are given in Appendixes A and B.

Implications of the digitalization of information processing

During the past two decades, as a result of the invention and development of a number of electronic components, circuits, and devices—such as the transistor, the magnetic-core memory, integrated circuits, etc.—it has become practicable and economical to process large volumes of data in digital form with high speed, accuracy, and reliability. We have witnessed a rapidly growing trend toward the use of digital systems in place of analog or continuous systems for purposes of computation, information processing, and control. Moreover, as a result of the availability of efficient, economical and reliable digital devices, modern information processing and control technology is becoming increasingly digital in nature, with all signs pointing toward a much bigger role for digital as compared with analog systems in the years ahead.

The transition from the analog and the continuous to the digital and the discrete has not yet been adequately reflected in the orientation of electrical engineering curricula. Many, or perhaps most, electrical engineering departments still lay a heavy stress on courses in continuous (in time, amplitude, and state) systems and devices, disregarding the fact that such courses are much less relevant to the needs of present technology, and certainly much less relevant to the needs of the future than they were 20 years ago, in the age of the vacuum tube and the amplidyne. The committee strongly feels that, in this regard, electrical engineering curricula are in need of a basic reorientation from the entirely analog and the continuous to reflect the digital and the discrete, and that electrical engineering departments should make a concentrated effort to prepare their students to deal with digital systems, be they computers, control systems, or special-purpose information- and data-processing systems.

How can such a reorientation be implemented? Clearly,

II. Skeleton of program showing recommended courses in computer science

Year	Term 1	Term 2
Freshman	...	Programming and numerical methods
Sophomore	...	...
Junior	Programming principles	Computation structures
Senior	Machines, languages, and algorithms	...

a wide-ranging shift in emphasis from the continuous to the discrete in electrical engineering curricula would present formidable problems that are not likely to be solved quickly or painlessly. Deeply entrenched attitudes will have to be changed, new knowledge and skills will have to be acquired, and new textbooks will have to be written. Indeed, it is beyond the scope of this report to analyze these problems fully and to suggest possible solutions to them. Thus, in what follows, the committee will restrict itself to making a few preliminary recommendations that suggest evolutionary changes in electrical engineering curricula. This section will discuss the addition of three new courses dealing wholly or in part with some of the basic aspects of discrete systems. The next section will discuss the digital reorientation of a number of existing courses.

New-course development. To provide a start toward the development of new courses that have a discrete state orientation, we discuss three possible courses as indicative of the direction that such development might take.

Course 1. Our first recommendation is that serious consideration be given to the development of a sophomore- or junior-level introductory course in circuits, systems, and signals, which would cover the fundamentals of both discrete and continuous systems. We envisage that, initially, such a course would be offered as an alternative to the traditional type of course in which the emphasis is wholly on the techniques of time- and frequency-domain analyses of linear, time-invariant, continuous-time circuits and systems. Eventually, courses of this new type would probably replace introductory courses of the more conventional nature.

An example of the type of course being recommended is that being developed at M.I.T. by Professors Athans, Dertouzos, and Mason, under the title, "Elements, Systems and Computation." In addition to covering the basic techniques of the analysis of linear, time-invariant, lumped-parameter networks and systems, this course also treats basic techniques for the study of nonlinear and discrete-state systems, and covers computational as well as analytic methods of problem solving in the context of such systems.

A controversial aspect of a course of this type is that its broader coverage of both continuous and discrete systems is attained necessarily at the cost of less depth in the treatment of various types of components and systems. For this reason, it may be preferable, in the longer run, to treat discrete systems separately in a course that would precede a course in continuous systems. Although this approach would represent a departure from the traditional order, it may well be more logical and more sound pedagogically.

Course 2. Our second recommendation relates to the inclusion of a new type of course, at the junior or senior level, that would be concerned chiefly with mathematical concepts and techniques central to the analysis and synthesis of discrete, as contrasted with continuous, systems. This course is listed in Table I as Introduction to Discrete Mathematics.

A representative set of subjects that might be included in a course of this type would include elements of set theory; Boolean algebra; elements of mathematical logic; elements of the theory of relations, groups, fields, and rings; elements of Galois theory; etc. A course of this type would serve essentially the same function in relation to discrete systems that the conventional courses in Laplace transforms, complex variables, linear algebra, etc., serve in relation to the analysis of linear time-invariant systems. Clearly, of course, the totality of the mathematical background needed for the analysis and synthesis of discrete systems cannot be provided in a single course.

A theoretically oriented student majoring in computer sciences might well take one or more courses in mathematics, in such subjects as abstract algebra, set theory, mathematical logic, group theory, etc., in preference to taking a single, less-specialized course of the type here being discussed. Thus, the committee's recommendation is intended primarily to point to a need in electrical engineering curricula for a broadly based course in the mathematics of discrete systems, which would be suitable for most electrical engineering students, not just for those majoring in computer science. A desirable first step in this direction may be accomplished by a revision of the usual two-year mathematics program that exists in almost all electrical engineering curricula (the calculus program), to a program of which one half is devoted largely to discrete mathematics and the second half to topics in continuous mathematics.

Course 3. Our third recommendation relates to the offering of a course in finite-state systems at the junior or senior level. The importance of such a course stems from the fact that finite-state systems constitute a very basic class of systems particularly well-suited for the introduction of such basic concepts as state, equivalence, identification, decomposition, etc. Furthermore, they are much better suited for computational purposes than continuous systems, and can frequently be used as approximate models for the latter. At present, several electrical engineering departments offer courses of this type, covering such topics as the characterization of finite-state systems, the notions of state and system equivalence, identification algorithms, decomposition techniques, synthesis techniques, etc.

Until a few years ago, the offering of courses on finite-state systems was hampered by the dearth of texts on this subject, a situation that is now changing. There are several very good undergraduate level texts on finite-state systems. The teaching of a course on this subject should be a relatively easy task for most electrical engineering professors. Consequently, the committee feels that every electrical engineering department should consider offering an elective course on finite-state systems as part of its regular curriculum.

Implementation

To introduce computer techniques in a meaningful way into traditional courses covering circuit theory, control, communication systems, and similar topics, the following sequence might be used in presenting subject matter: theory, analytical methods of solution, numerical algorithms, and computational examples. Some general recommendations are outlined in the following; these recommendations presuppose a familiarity with programming principles and elementary numerical methods.

1. The first course in electrical engineering (usually in the sophomore year) should be modified to incorporate the use of computers as a tool. A problem-oriented program having a special language might be used to work exercises relatively early in the course, without requiring

a detailed knowledge of computer programming.

2. Major revisions might be made in the method of presentation for certain courses, particularly those in the systems area. For programs in control theory and communication systems, for example, this approach might involve changes in emphasis of some of the traditional material and the introduction of new material related to computer operation and limitations.

3. Since the purpose of courses in the systems area is to develop an understanding of the behavior of these systems, it would be desirable to make available to the students as analysis and design aids certain fairly elaborate specialized computer programs with provision for graphic output. Computer-generated results would thus be provided without the large investment of the student's time that would be required were he forced to write and debug all of the necessary programs.

4. The academic program should help develop a more thorough understanding of programming techniques and the limitations of numerical methods of simulation, particularly in those areas in which the computer is a major factor in the practice of modern engineering, either as a design tool or as an important part of the system.

5. The use of computers for system simulation should be encouraged as a valuable supplement to laboratory experiments with physical elements.

Computer use for simulated laboratory experiments

Digital computer simulation of devices and systems can provide a valuable supplement to laboratory experiments with physical elements. Simulation studies, provided that adequate software is available, can also be used very effectively as alternatives to some problem sessions and homework exercises. It is recommended that such computer experiments on idealized models of physical devices be introduced into the laboratory program early in the curriculum. The essential features of the behavior of many types of systems can sometimes be explored more readily in this way than by actual experiments.

Idealized models can, of course, be nonlinear and thus can provide quite realistic representations of the true device characteristics. Some advantages of a computer study are the ease with which the model parameters can be varied over a wide range without damage to the components, the ability to compute sensitivity coefficients and make a worst-case analysis, and the ability to generate and plot performance curves directly for nonlinear as well as linear systems without tedious experimental tests or the drudgery of repeated hand computations. Furthermore, this approach allows a considerable degree of individual initiative to be exercised by the student in the design of the system model to be simulated.

Observation of the behavior of the actual physical system is very important, and experiments on real devices and systems should clearly be retained. Both types of experiments are significant in different ways in helping to develop an intuitive feeling for system behavior; a balance should be maintained between actual and simulated experiments. A combination of both will be more stimulating than either type alone, and has the added advantage of providing a basis for appreciating the differences between the analysis of an idealized model and the behavior of the real device.

For example, digital simulation of models of electronic circuits can be a significant adjunct to normal electronics laboratory experiments. A number of quite elaborate electronic circuits analysis computer programs are available or are being developed. Although many of these have serious deficiencies from an educational viewpoint, there is some expectation that this will be rectified in the relatively near future. An electronic circuit simulator, such as ECAP, when supplemented by a graphical output routine can provide the basis for some very useful simulation studies in this field. Examples might include the study of transistor amplifier operating-point stability with respect to parameter variations, the transient and frequency response characteristics of pulse amplifiers, and oscillation phenomena.

Educational software

The most desirable types of specialized software that should be available in the computer library can be divided into several general categories:

1. Mathematical subroutines. Examples include graphic output subroutines and programs to solve simultaneous sets of linear equations, to find the roots of polynomials, and to solve sets of ordinary differential equations. These subroutines are presently available at almost all computer centers. They are far from being sufficient, however.

2. More elaborate programs to facilitate special types of analysis. Examples are frequency response, root-locus and transient-solution plotting, Fourier-series analysis routines, parameter optimization routines, and some statistical analysis routines.

3. Problem-oriented programs with special language facilities. Examples of such programs are analog system simulators, such as MIMIC and CSMP; digital system simulators, such as BLODI; and electronic circuit simulators, such as ECAP. Another significant example is JOBSHOP, which was developed by W. H. Huggins at The Johns Hopkins University, as a simulator for the circuit design process. Much remains to be done in the development of suitable software for educational purposes. In addition, information concerning the availability of the computer programs that do exist, and their documentation, leaves a great deal to be desired.

Closing comments

The recommendations presented in this article relate to what the committee believes are the central issues in the impact of computers and computer sciences on electrical engineering education. These are (1) the need for computer science programs in electrical engineering, (2) the need for greater emphasis on discrete systems in electrical engineering curricula, and (3) the need for modifying the content and underlying philosophy of basic electrical engineering courses, particularly in circuits and systems, to interweave the use of computers for analysis and design with the development of basic theory.

These issues are probably the most pressing of the many questions and problems facing electrical engineering education today. They are by no means the only issues arising out of the advent of the computer age; clearly, the use of computers will have to be stressed not only in courses in circuits and systems but, more generally, in all areas in electrical engineering in which computers can be an effective tool for analysis, design, or simulation. We have said nothing concerning the roughly three years of studies constituting the portion of the B.S. program that reflects the general base of electrical engineering. However, we do stress that attention must be given to the revision of introductory courses in mathematics, physics, and other basic fields, with a view to increasing the emphasis on algorithmic and numerical techniques in such courses. Also, the traditional role of laboratory courses must be re-examined, in the light of the possibility of using computers as simulators of physical systems. Already, in many instances, greater insight into system behavior may be obtained by studying its performance with the aid of a computer than by measuring the physical variables and parameters associated with it. This will be even more true in the future.

It hardly needs saying that computers and computer sciences are, and will be, of considerable concern to many disciplines in addition to electrical engineering, and electrical engineering departments will have to cooperate closely with other academic departments, especially computer sciences and mathematics departments, both in instruction and in research in computers and related areas.

During our study, we have maintained liaison with the ACM Curriculum Committee on Computer Sciences through E. J. McCluskey, and we are especially indebted to William Viavant of that committee for his assistance. We also wish to acknowledge the support of our efforts by the National Science Foundation through the Commission on Engineering Education, and its executive director, Newman A. Hall.

Appendix: Some electrical engineering curricula that include computer science courses

A. College of Engineering, University of California, Berkeley

B.S. Computer Science Program

Year and Course	Quarter Hours
Freshman	
Mathematics	12
Chemistry	12
Physics	7
Electives[a]	14
Sophomore	
Mathematics	12
Physics	12
Electives[a]	21
Junior	
Electric circuits	8
Electronic circuits	5
Electronics and circuits laboratory	6
Linear systems analysis	4
Computers and information processing	4
Restricted[b] and technical[c] electives / Humanistic-social[d]	18
Senior	
Switching and computer circuits	6
Digital computer systems	7
Laboratory	2
Restricted[b] and technical[c] electives[b] / Humanistic-social[d]	30
Total:	180

[a] The electives for the freshman and sophomore years include at least 15 hours of humanities or social sciences, plus

Computers and their applications	4
Introduction to electronic systems, circuits, and devices	4
Engineering mechanics	4
Properties of materials	

[b] Restricted electives: three courses from an available list, including mathematics, physics, engineering courses.

[c] Technical elective: 25 units of upper division computer science, engineering, mathematics, physics, statistics, or other natural science courses.

[d] Humanistic-social: Total in the program must meet minimum College requirements.

B. Department of Electrical Engineering, Massachusetts Institute of Technology

S.B. in Electrical Engineering,[a] Computer Science Program

Year and Course	Credit Hours[e]
Freshman	
Calculus	24
Chemistry	12
Physics	24
Introduction to automatic computation	6
Humanities	18
Elective	6
Sophomore	
Physics[b]	12
Physics	12
Elements, systems, and computation[b]	12
Elements, systems, and computation	12
Programming linguistics[c]	12
Elective[b]	12
Humanities	18
Junior	
Circuits, signals and systems	12
Electromagnetic fields and energy	12
Computation structures[c]	12
Computer systems[c]	12
Electives[d]	24
Humanities	18
Senior	
Electives[d]	60
Humanities	18
Thesis	12
Total:	360

[a] An unofficial curriculum presently under consideration.

[b] Subjects to meet an M.I.T. "science distribution requirement."

[c] Basic computer science courses now under development.

[d] A variety of suitable computer science elective subjects is currently available.

[e] Three credit hours represent approximately one semester contact hour.

IEEE publications

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special publications

Scanning the issues

City Noise and Antennas. New York City has been found once again to excel in an area heretofore unsuspected by the common man. An experimental program to determine the characteristics of city noise and its effect on airborne UHF antennas shows that the noise power density in the UHF band is 5 to 6 dB higher for New York City than for other East Coast cities in the United States. Thus, New Yorkers may now proudly lift their heads, as they are showered with that other form of noise pollution from the numerous aircraft flying overhead, and say to themselves, "At least, *we* are fouling up *their* UHF antennas more than anybody else!"

The effect of city noise upon airborne antenna noise level has been observed in the past, but up until now no analytic description of this source has been presented. George Ploussios of the M.I.T. Lincoln Laboratory has now filled in this significant gap for us.

Airborne UHF antennas, he writes, are typically low-gain devices that accept incoming energy without discrimination from large angular sectors. In computing the noise level at the airborne antenna terminal one must consider in conjunction with the antenna pattern the possible noise sources originating from the atmosphere, space, the aircraft itself, and from vast areas of the earth. These include atmospherics, galactic noise, precipitation static, blackbody radiation from the earth, and ground, aircraft RFI, and city noise. Characteristics of the first four sources have been partially covered in the literature. Noise from RFI cannot be generalized and must be considered separately for each particular installation.

Noise generated in industrial areas is considered as either coherent or incoherent. The latter includes radiation from communication equipment, radar, navigational aids, etc., and are generally classified as RFI. Incoherent man-made noise comes primarily from ignition systems, power lines, and other electric machinery. This energy, which is impulsive in character, is the subject of Ploussios' study. He describes his effort to characterize this city noise in a form that can be applied in computing antenna noise temperature for an arbitrary antenna.

Denizens of cities other than New York may be interested in calculating how they rate in this part of the noise pollution spectrum. We in New York suspected all along how it would turn out. Of course, we would be best. Living and working, as we do, in the publishing and advertising capital of the world, we suspect that we excel in producing *all* forms of noise. (G. Ploussios, "City Noise and Its Effect Upon Airborne Antenna Noise Temperatures at UHF," *IEEE Trans. on Aerospace and Electronic Systems*, January 1968.)

University vs. Industry. The bell rings and the next round of that long-winded battle between industry and the university on how the students should be turned out begins. The famous fight in which Sullivan beat Jake Kilrain only went on for 75 rounds (i.e., exhaustion), but the university–industry fight threatens to go on forever (i.e., until the state of utter boredom sets in). As H. W. Farris says, the extent to which engineering curricula should be responsive to the needs or demands of industry can be a hotly debated issue. It is so, of course, for very good reasons. With engineering enrollments declining at the undergraduate level, there is a lot for both industry and the university to worry about. Farris considers a variety of methods for getting better communication and interaction between the academic and industrial worlds, and those who care will want to read him.

The 1889 Sullivan–Kilrain fight, by the way, was the last championship bare knuckles bout; so it should come as no shock to realize that the punches in the university–industry fight are well-padded. It is an interesting struggle to observe, nonetheless, for those who like to read between the lines or, maybe we should say, between the rounds. (H. W. Farris, "University–Industry Relations—Needs and Methods," *IEEE Trans. on Education*, December 1967.)

Is Power Dead? Another important aspect of the university–industry relationship is explored in a paper that deals with the question of whether or not universities have been guiding students away from the electric power industry. The authors note that in the late 1950s and early 1960s nearly all of the national meetings of the power industry engineers included sessions on the general theme of the declining interest in power engineering by the faculties and students of universities. Frequently, the electrical engineering faculty were portrayed as having abandoned the power field for more profitable government-sponsored research projects.

The discussions brought to a focus a problem that concerns the entire electrical engineering profession, namely, that the needs of a major electrical industry are not being satisfied. Several universities, the authors write, recognized the problem and have tried to incorporate various power programs into the modern electrical engineering curriculum. As a consequence, some excellent programs in electric power have been established in major universities.

The authors are concerned with another factor, however, that they say could, in the long run, eclipse all others in its total contribution to the industry, not only in terms of its contributions of useful ideas but also in providing a supply of able, interested engineers.

Almost every problem one can name in power engineering, the authors claim, can benefit from the technologies of others. In short, they urge that the university play a role in cross-fertilization, getting staff members with capabilities in diverse fields to find new applications in the power field. The universities, the authors say, require only two things in order to attack the problems of the power industry. First, they need to be told what those problems are and, second, they need financial support to pursue the solutions. It is about as simple as that. There is one other ingredient that makes the whole thing work. The university needs a few able and dedicated people who have a knowledge and interest in the power field and who can pull all these forces together. The results, attested to by practical examples from the authors, are said to be most gratifying. The ideas of these authors may merit more than a passing consideration by those who are concerned with the future of the power industry, whether or not they are in a university or industry. (P. M. Anderson and A. A. Fouad, "Is Power Dead in the University?" *IEEE Trans. on Education*, December 1967.)

Meshless Storage Tube. Those in the display field will be interested in the development of a simplified meshless storage tube reported in the December issue of the IEEE Transactions on Electron Devices. The tube uses a single-layer dielectric storage target deposited over a transparent conductive coating on a glass faceplate. The dielectric layer serves the dual purpose of providing bistable charge storage and light output.

Those who are not in the display field may also find the historical account of the development of bistable tubes of interest. One of the most significant steps in the history of bistable tubes, it is said, was the development by Andrew Haeff of the device shown in simplified form in Fig. 1. In this Haeff tube, which may be considered the point of departure for the new meshless tube, a writing gun forms a charge image on a dielectric storage layer that controls the transmission of flood current to the phosphor screen.

The storage mechanism in these tubes depends on the fact that the flooding electrons arrive at the target with different velocities in different areas. Where the target background is unwritten and is at a low potential, the flooding electrons bombard the target with low velocity, and a low secondary emission ratio results. These areas charge negative by simple collection of flood current.

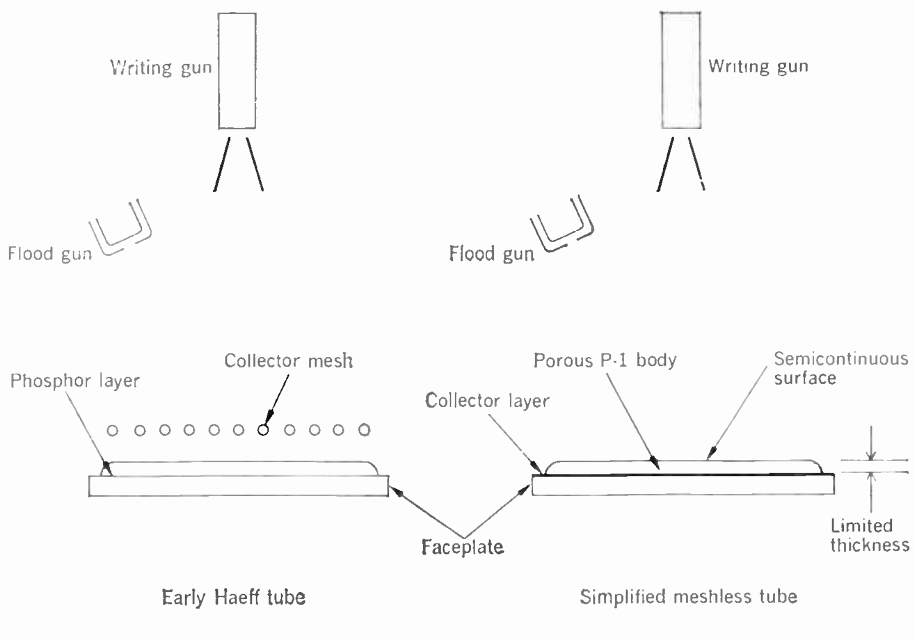
Where areas of the target are written and are at a higher potential, flood current bombardment is at a higher velocity, and a high secondary emission ratio results. These areas charge positive by loss of secondary electrons. The result is that two adjacent target areas may be charged in opposite directions by flood current bombardment from a single source. This results in the bistability of a good secondary emitting surface under flood current bombardment.

A special feature of the Haeff tube is that the collector mesh actually lies on the dielectric surface, in contact with it. It is apparently necessary to interrupt a bistable storage surface by some mechanical or electrical means, such as a barrier grid or a porous, rough, electrically discontinuous dielectric layer, to prevent the stored image from spreading or shrinking. The contacting collector mesh in this device appears to serve this purpose, among other purposes, at least in the commercially available tubes of this type, since stored writing of part of the dielectric area within a collector mesh square opening is not obtained.

The principal structural feature of the new storage tube is the formation of a semicontinuous porous dielectric layer that will not sustain migration of the boundary of the stored charge image transversely across the target surface, because of the electrical and mechanical discontinuity of the target microstructure.

In the meshless tube structure shown in Fig. 1, target porosity and the very small spacing from the collector to the target surface act together to form a strong collecting field, and the semicontinuous surface prevents image boundary migration under flood current bombardment. The target layer is thick enough to sustain a fairly high operating voltage for reasonable brightness, but thin enough to form the porous and semicontinuous microstructure. (R. H. Anderson, "A Simplified Direct-Viewing Bistable Storage Tube," *IEEE Trans. on Electron Devices*, December 1967.)

FIGURE 1. New meshless storage tube, compared with early Haeff tube.



Laser Engineering. Two recent issues of the IEEE Journal of Quantum Electronics will be of interest to those who are concerned with laser developments. The November issue contains nearly 40 out of the original 94 papers presented at the 1967 Conference on Laser Engineering and Applications. Among the selected papers, for instance, is a report from authors at the Moscow Institute of Radio Engineering and Electronics on the use of lasers in measurements of the stimulated emission cross section. Other papers are on all-weather terrestrial range finders, a laser satellite ranging system, an underwater range-gated photooptical system, a traveling-wave laser gyrocompass, and many others of practical interest.

The December issue contains a "Bibliography of Laser Devices," the continuation of a series of such bibliographies being carried out by K. Tomiyasu. Because the laser literature has grown so enormously, Tomiyasu restricts this new listing to cover only laser devices. Even at that, the list includes 223 items. (*IEEE Journal of Quantum Electronics*, November and December 1967.)

Advance abstracts

The IEEE publications listed and abstracted below will be available shortly. Single copies may be ordered from IEEE, 345 East 47 Street, New York, N.Y. 10017. Prices are listed with the abstracts of each publication; libraries and nonmembers outside the United States and Canada should add $0.50. (M—Members; L—Libraries; NM—Nonmembers.)

Copies of individual articles are not available from IEEE but may be purchased from the Engineering Societies Library at the foregoing address.

Proceedings of the IEEE
IEEE Transactions and Journals
- Antennas and Propagation
- Audio and Electroacoustics
- Computers
- Electron Devices
- Microwave Theory and Techniques
- Nuclear Science
- Parts, Materials and Packaging
- Power Apparatus and Systems
- Quantum Electronics

Proceedings of the IEEE

Vol. 56, no. 3, March 1968
M—$2.50; L—$3.75; NM—$5.00

Signal Processing in a Nonperiodically Time-Varying Magnetoelastic Medium, *B. A. Auld, J. H. Collins, H. T. Zapp*—Wave propagation in a nonperiodically time-varying medium provides a means for realizing in simple physical structures a variety of signal-processing operations, such as frequency translation and coding, variable delay recall, gating, time-scale stretching or shrinking, and time reversal. The use of low-velocity modes, such as acoustic, spin, or magnetoelastic waves in solids, reduces the length of the propagation structure required to less than an inch.

A general review is given of the principles of wave propagation in a spatially uniform medium with nonperiodic time variation. Both abrupt and gradual time variations are discussed. Illustrations are given for the cases of spin-wave and magnetoelastic-wave propagation, and signal-processing operations in these media are explained.

Consideration is given to the problem of spin-wave propagation in a time- and space-varying magnetic field of the form encountered in experiments and it is shown that a simple separated variable solution exists. For the more difficult problem of magnetoelastic propagation with both space and time variations, an approximate space–time ray theory is described. Experimental results for pulsed-field processing of spin and magnetoelastic waves are given and related to the theory.

Image-Storage Panels Based on Field-Effect Control of Conductivity, *B. Kazan, J. S. Winslow*—Using the principle of field-effect conductivity control, a new method of image storage has been demonstrated. Based on this, a new type of solid-state image panel has been developed capable of producing a stored luminescent image. This employs an electroluminescent powder layer for generation of the output image and a ZnO powder layer for control and storage purposes. In operation the exposed ZnO surface is first uniformly corona charged to a negative potential to reduce its conductivity and "erase" old information. Then, the panel is exposed to an optical image which discharges local areas, producing a stored charge pattern on the ZnO surface. In accordance with this charge pattern, a conductivity pattern is created in the ZnO layer, which in turn controls the luminescent output of corresponding areas of the adjacent phosphor layer. For producing a stored image, approximately one microjoule/cm^2 of input radiation in the wavelength range of 3500 to 4000 Å is required. Reciprocity exists between the exposure time and the radiation level. Stored images have a brightness as high as 20 foot-lamberts and a maximum contrast ratio of about 100 to 1 and exhibit good halftones. Although a halftone output image can be retained for periods of about an hour, it can be rapidly erased when desired by recharging the ZnO surface to a uniform negative potential. Present panels are 12 by 12 inches in size and have a limiting resolution between 400 and 800 television lines.

A Model for Electromagnetic Propagation in the Lithosphere, *F. K. Schwering, D. W. Peterson, S. B. Levin*—The propagation properties of a crustal waveguide are derived using a model where dielectric constant and conductivity increase with depth according to a simple algebraic relation. The model is more realistic and consistent with currently available geological information and with reasonable extrapolations of crustal properties than are previously treated models. The mathematical analysis, moreover, is straightforward and rigorous, leading to an explicit analytical solution in the form of a mode expansion, the individual terms of which can be written in closed form. Numerical evaluation of the model leads to a total attenuation rate (for the dominant mode) of 0.256 dB/km for a frequency of 1 kHz. A geologically critical attribute of the model is a positive temperature gradient with depth as the principal controlling influence on the electric profile. A temperature gradient lower than the one used in constructing the model would significantly reduce the attenuation rate.

Covariant Descriptions of Bianisotropic Media, *D. K. Cheng, J.-A. Kong*—It is suggested that a medium in which the field vectors **D** and **H** depend on both **E** and **B**, but are parallel to neither, be described as bianisotropic. A moving medium, even if it is isotropic in its rest frame, then appears bianisotropic to the laboratory observer. The transformation formulas are given for the constitutive relations of a bianisotropic medium between inertial frames in relative motion. It circumvents the necessity of knowing the constitutive relations of the medium in its rest frame. As an application of the general formulation, the dispersion relations for plane waves in a bianisotropic medium are derived.

A General Mechanical Model for $|f|^\alpha$ Spectra Density Random Noise with Special Reference to Flicker Noise $1/|f|$, *D. Halford*—Any class of reasonable time-dependent perturbations occurring at random, under certain internal constraints, generates random noise having a spectral density varying as $|f|^\alpha$ over an arbitrarily large range of spectral frequency f only for $-2 \leq \alpha \leq 0$. A class is the set of all perturbations that are equivalent under some individual independent scaling of amplitude, scaling of time, and translation of time. A subclass is characterized by $P(\tau)$ and $A^2(\tau)$, where $P(\tau)$ is the lifetime probability density and $A^2(\tau)$ is a mean-square amplitude of perturbations having lifetime τ. For a given class, $|f|^{\alpha_\infty}$ and $|f|^{\alpha_0}$ are the frequency-smoothed laws in the limits of infinite and zero frequencies, respectively. Any reasonable perturbation has $\alpha_\infty \leq -2$ and $\alpha_0 \geq 0$. To generate random noise having an $|f|^\alpha$ law over an arbitrarily large range of f from a subclass chosen from any class characterized by α_∞ and α_0, it is necessary that $\alpha_\infty \leq \alpha \leq \alpha_0$. For $\alpha_\infty < \alpha < \alpha_0$, it is necessary and sufficient that such subclasses satisfy the condition, $P(\tau)A^2(\tau) \approx B\tau^{-\alpha-3}$ with B constant, over a suitable range of τ, and that $P(\tau)A^2(\tau)$ not be larger than $B\tau^{-\alpha-3}$ outside the range. This general mechanical model is of immediate value in the formulation and criticism of specific physical models of $|f|^\alpha$ noise, including flicker noise, and in computer simulation of $|f|^\alpha$ noise.

Analysis of Two-Port Magnetoelastic Delay Lines as Pulse-Compression Filters, *J. H. Collins, H. R. Zapp*—A critical review is given of the properties of magnetoelastic delay lines, employing yttrium iron garnet (YIG) and having physical distinct input and output ports. Attention is directed to two configurations involving the materials YIG and yttrium aluminum garnet (YAG), namely, the YAG($n\lambda_B/4$)–YIG–YAG($n\lambda_B/4$) employing YAG quarter-wave plates $\lambda_B/4$, and the YIG–YAG–YIG structures. These offer the highest isolation between input and output ports coupled with the lowest insertion loss for magnetoelastic waves, under specified conditions of microwave frequency and delay. The transfer functions through the YAG material are derived in each configuration for the cases of (1) imperfect matching between the acoustic characteristic impedances of YIG and YAG, with perfect optical bonding, and (2) imperfect optical bonding. Conventional matched filter theory is used to evaluate the time response of each magnetoelastic delay line, assuming linear variation of delay with frequency, to a linearly frequency-modulated pulse. It is established that the configuration employing quarter-wave plates gives desirable weighting of the main pulse. However, a spurious echo of unacceptable level exists when a reasonable bandwidth, which is delayed approximately by an acoustic round trip in the $n\lambda_B/4$ plate, is employed. Analysis shows that this difficulty does not arise for the YIG–YAG–YIG configuration. However, an external weighting network is required for range sidelobe reduction.

Proceedings Letters

Because letters are published in PROCEEDINGS as soon as possible after receipt, necessitating a late closing date, we are unable to list here the letters in the March issue. This will appear in the next issue of SPECTRUM. Listed below are the letters from vol. 56, no. 2, February 1968.

drawback that one driver is required per 50 passengers, contrasted to one or two trainmen per 1000 passengers. Buses also must contain their own power plant, which can contribute to air pollution. On the other hand, buses are mass produced today and require less supporting equipment than does a railroad operation.

An extended treatise on this subject would involve far more than can be covered in this letter. It would be necessary to show how "bus stations" could be built to assure rapid loading and remerging into a traffic stream, traffic projections for a given locale, and thorough economic studies. This is all well beyond my intended scope.

As an electrical engineer, I am loathe to say that we have the technology today to handle the problems associated with moving people about a metropolis, especially since it involves very few electrical ones, whereas Dr. Michaels' proposal would involve moving people by electric power and controlling this movement electronically. However, as a taxpayer and as a commuter, I strongly desire an economical and convenient solution. Except where other factors, such as existing facilities or unusual geographic conditions, are important, I cannot believe that rail transportation is the answer.

J. Arthur Hirsch, Jr.
Indianapolis, Ind.

Mr. Hirsch advocates the use of buses on a separate right of way as preferable to railroad rapid-transit trains on a private right of way for the movement of large numbers of people at high schedule speeds.

In the second paragraph of his letter he claims comparable economy for these two methods of moving people. Although I admit that buses can operate on an exclusive right of way, I hasten to point out that this type of operation is fantastically expensive because of (1) the exorbitant cost of providing exclusive freeway lanes for buses alone, and (2) the astronomical cost of labor for one driver per 50 bus passengers: The very point of my article is that the only present technically and financially feasible method of furnishing the capacity to move large numbers of people efficiently in metropolitan areas necessary to prevent the traffic strangulation of the large cities is the high-speed electric railroad on a private right of way. The bus, when employed on a separate right of way, although technically possible, is most certainly not economically feasible.

In the ninth paragraph of his letter, Mr. Hirsch admitted that one bus driver is needed per 50 passengers. However, his statement that one or two trainmen are needed per 1000 passengers shows that his thinking is not current, because this is just not so. The Expo-Express operated very successfully last summer at Expo '67 in Montreal as a fully automated railroad rapid-transit system using no operating personnel on board.

It is clear that, strictly on the basis of operating cost alone, any bus system should be ruled out in favor of the presently available automatic railroad rapid-transit system for moving large numbers of people economically—as well as rapidly, safely, comfortably, and reliably.

Mr. Hirsch's claim that a 90-second headway for high-speed train operation has never been tried is also completely erroneous. This headway has been commonplace in railroad rapid transit for more than 50 years. Apparently Mr. Hirsch never stood upon the platform of the Times Square station of the B.M.T. division of the New York subways, among many others that can be chosen, and counted the trains departing on the express track between the hours of 5 and 6 P.M.

For comparative purposes, it may be noted that even in 1920 suburban trains seating 848 passengers each departed at headways of 2½ minutes from Liverpool Street station in London on the Great Eastern Railway. Furthermore, this was a *steam-locomotive-hauled* operation wholly without the benefits of modern computer-type centralized traffic control. The foregoing figures are taken from Allen's *Modern Railways.*[1]

It is true that buses can be designed to operate at 80 mi/h (128 km/h) if necessary. However, it is extremely dangerous for them to operate at this speed with the headway of only 2 seconds that Mr. Hirsch recommends. At this speed and headway the spacing between successive buses would be 235 feet.

I have discussed this situation with attorneys of the United States Department of Justice who are charged with litigation involving motor vehicle accidents upon highways of all types, including freeways. The result indicated that the operating conditions sanctioned by Mr. Hirsch would cause a prohibitive degree of danger to the buses. It is an established fact that at 60 mi/h under optimum conditions of visibility and a dry pavement, and assuming a very short reaction time of ½ second, 366 feet are required to bring the average motor vehicle to a stop before striking a fixed object. At 80 mi/h the stopping distance is much longer.

Therefore, to allow only 235 feet of space between buses at 80 mi/h is grossly negligent and foolhardy. The bus driver, being human, is certainly not infallible. An accident at this speed and spacing can cause an accordian-like pileup of buses following, with disastrous consequences.

In a balanced transit system, transferring from one mode of transportation to another is unavoidable, but it is a small price to pay for efficient transportation. Jack E. Rupp, manager of marketing planning, General Railway Signal Company, Rochester, N.Y., is quoted in an article by Marc Raizman in *Electronic News*[2] as saying that "Americans will have to come to accept that what is sought is a 'balanced transportation system,' and that this will require changes from one method of conveyance to another to achieve the best, the most economical, and the fastest transportation in a system. Door-to-door service without changes won't be possible or practical."

The door-to-door bus service that Mr. Hirsch advocates is inherently not capable of moving large numbers of people both rapidly and economically. The best way to accomplish this task is to use a balanced transit system in which the successful employment of each mode of transit, used for the type of job it can do best, is integrated into an effective and efficient overall system.

I am pleased to receive Mr. Hirsch's reaction to my article, and am grateful for this opportunity to respond. I hope that our letters will provoke additional thought among other readers on this very important subject of the efficient movement of people in metropolitan areas.

Edward L. Michaels
University of Houston, Tex.

1. Allen, C. J., *Modern Railways (Their Engineering, Equipment and Operation)*. London: Naber and Naber, Ltd., 1959.
2. Raizman, M., "Rapid transit can't wait for new, exotic concepts," *Electron. News*, Nov. 20, 1967.

Correction noted

It has been most interesting to read the article on "Electron Devices in Science and Technology" by R. Kompfner in the September 1967 issue of IEEE SPECTRUM.

Although E. Ruska was a major contributor to the development of the electron microscope, he was not its inventor, as was stated on pages 49 and 52.

The invention of the electron microscope is due to Dr. Reinhold Rüdenberg, now deceased, formerly Gordon McKay Professor of Electrical Engineering at Harvard University. The story of the invention when Rüdenberg was associated with Siemens in Germany in 1931 and the subsequent delay of recognition through the long war period is a fascinating one, which will perhaps be related in detail some day.

For the present, two short articles briefly give the facts.[1,2] The second reference cites the original patents of May 1931.

Graham W. Hoffman
The University of Tennessee
Knoxville, Tenn.

1. Rüdenberg, R., "Elektronenmikroskop," *Die Naturwissenschaften*, vol. 20, p. 522, 1932.
2. Rüdenberg, R., "The early history of the electron microscope," *J. Appl. Phys.*, vol. 14, p. 434, Aug. 1943.

A novel switch!

I was interested in the letter from Eric Weissman that appeared in the January 1968 issue of IEEE SPECTRUM entitled "Solution for Power Failures?"

Mr. Weissman's proposal sounds interesting and there could be an added advantage that he failed to mention. The addition of a single-pole double-throw switch to switch the primary of his transformer to a house current connection would also provide we inhabitants of the frozen north a method of charging our batteries overnight. This would insure that more of us would arrive at our places of employment on time when the mercury is huddling in the bulb at the bottom of the thermometer.

G. Herbert Coddington
Brewerton, N.Y.

Contributions to this department should be addressed as follows: Technical Correspondence, IEEE Spectrum, 345 East 47 Street, New York, N.Y. 10017. It will be assumed that letters so addressed are intended for publication.