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IEEE spectrum

features

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THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

departments

the cover

Even though he may suffer feelings of confusion and absurdity, man must evolve a new concept of his relationship with machines, which up till now have automated his own human powers. In the article beginning on page 87, it is argued that through widespread artificial intelligence it will be possible to move toward evolutionary man–machine dialogue that would work for the enhancement of man.

Spectral lines

Copyright problems. The concept of ownership may seem to be a peculiar one to use in connection with new scientific and technical knowledge. Yet such knowledge is certainly of great value and its originator deserves to be rewarded. The legal means for protecting the intellectual property of an author is the copyright. Ideally, it is a device for encouraging the free flow of information, since, by protecting the rights of the originator, it encourages him to invest his time and energy in putting his knowledge and ideas in a written form and thus making them available to others.

Similarly, copyright procedures should also serve to encourage a publisher to produce and circulate the written work by protecting his economic investment in its preparation for publication. Although the author's and the publisher's interests are by no means identical, they both deserve protection for the investment that each of them makes.

The needs and welfare of the public also must be considered, however. As it is usually in the best interest of society to have new information disseminated to all who can benefit from it, and as freely as possible, the copyright protection afforded the author and publisher should not impede the rapid and widespread flow of such information. Also, it has been recognized that, in some areas, the free flow of information is so important that the rights of the copyright holder do not take precedence. In the United States of America, for example, under the "fair use" exemption, educators have been allowed to reproduce, in reasonably small quantities, copies of copyrighted material for instructional purposes without obtaining the permission of the copyright holder.

Present copyright procedures in the United States and other countries are being re-examined because of the newly developed capability to produce rapid and inexpensive reproductions of information practically simultaneously for a great number of users who may be at different locations. Various technological advances, such as improved photoreproduction techniques, computers, and efficient high-capacity communication channels, make many of the conventional copyright procedures inapplicable. New procedures are needed to ensure that the protection of the rights of the copyright holder does not result in a stifling of experimentation with new information-dissemination techniques. At present, a proposed revision of the almost 60-year-old copyright laws is under study in the United States Senate (Senate Bill S. 597) and there is a strong disagreement among interested parties as to what its effect would be on modern information-dissemination methods.

Most professional societies such as the IEEE copyright their publications. Perhaps their major reasons for doing so are to prevent the republication of material without the consent of the author and to prevent republication of material bearing the organization's name in an unprofessional manner. However, if republication proposals meet the appropriate requirements, permission to duplicate or republish is given unhesitatingly, usually without a fee. But it is not difficult to imagine a situation in which freely given permission to republish could, with the use of the new technology, result in the erosion of the economic base on which the society operates. For example, the IEEE's published output could be readily put in the form of a machine-readable tape either by the Institute or another organization. The question of reproduction rights then could become quite crucial, since hard copies might be produced from the tape so inexpensively that a user could obtain all of the technical literature output of the IEEE without becoming a member.

From this standpoint, it could well be argued that the IEEE should take a hard line and attempt to maintain tight control over the republication of its literature, or even over its input into a computer-based information system. On the other hand, it should not be forgotten that a fundamental objective of the Institute is to foster the rapid and effective dissemination of scientific and technical information. It would certainly not be appropriate for the Institute to attempt to retard the development of new techniques which would result in more widespread use of the information it publishes. If such developments threaten the financial base of the Institute, it is clear that steps would need to be taken to protect its economic viability. However, such steps should not include measures that impede the experimentation and studies needed to develop new and better means of information dissemination.

F. Karl Willenbrock

Authors

Electron devices in science and technology (page 47)

R. Kompfner is presently the associate executive director for research in the Communications Sciences Division at Bell Telephone Laboratories, Inc., Holmdel, N.J. He joined the technical staff at Bell in 1951, was named director of electronics research in 1955, director of electronics and radio research in 1957, and assumed his present post in 1962.

He was awarded the Diplom-Ingenieur degree from the Technische Hochschule, Vienna, in 1933, and he practiced architecture in London until 1941—meanwhile pursuing physics and radio engineering as a hobby. In 1941, while working for the British Admiralty, he attended Birmingham University, and there invented the traveling-wave tube. Between 1944 and 1951 he did further work for the British Government. He received the Ph.D. degree from Oxford in the latter year.

Among his many honors are the Duddell Medal of the Physical Society of England, the AIEE David Sarnoff Award, and the Franklin Institute's Stuart Ballantine Medal. He is a Fellow of the Physical Society and a member of the National Academy of Engineering.

Numerical solution of electromagnetic problems (page 53)

R. L. Tanner (F) is presently serving as senior staff scientist at Granger Associates, Palo Alto, Calif. He is the inventor of the wire-grid Luneburg lens HF antenna, among many others, and he holds over a dozen patents in the field.

He received the B.S., M.S., and Ph.D. degrees, all in electrical engineering, from Stanford University, in 1944, 1947, and 1953, respectively. Between 1944 and 1946 he served in the U.S. Signal Corps. In 1947 he joined the Electrical Engineering Department of the University of Washington, Seattle, where he taught courses in electronics and communication engineering. During 1950 he was engaged in antenna research at the Boeing Aircraft Company, Seattle, and he joined Stanford Research Institute in the following year. There he was involved in research in a number of areas in the field of antennas and related systems problems.

Dr. Tanner became head of the Antenna Research Group of the Electromagnetics Laboratory at Stanford Research Institute in 1956 and, four years later, he was named manager. In 1961 he joined TRG, Inc., as vice president and general manager of the Western Division, and he joined Granger this year.

He is a member of Phi Beta Kappa, Tau Beta Pi, Sigma Xi, and the Scientific Research Society of America.

M. G. Andreasen (M) is a senior research engineer with Granger Associates and is engaged in the use of digital computer techniques for antenna design.

He received the M.S. and Lic. Techn. degrees, in 1952 and 1956, respectively, from the Technical University of Denmark. Between 1952 and 1956, as a research assistant at the university, he did research on plane reflectors for maximum gain, polarization-transforming reflectors, and radomes; and he also gave a series of lectures on microwave circuit theory. For the next two years he worked on antennas for low sidelobes and on components for multimode waveguide systems at Siemens & Halske, Munich. Subsequently, he served as a field engineer with the Danish Post and Telegraph Administration and, in 1959, he joined Stanford Research Institute as a senior research engineer. There he developed the basic design for the wire-grid Luneburg lens antenna.

Between 1961 and 1967, he worked for TRG as a senior supervisory engineer. At TRG he expanded the use of digital computer techniques to the solution of numerous problems of electromagnetic theory, and he also developed a computer program that evaluates the current distribution, the input impedance, and the radiation pattern of a wire antenna of arbitrary geometry.

Patterns of U.S. energy consumption to 1980 (page 81)

William A. Vogely is assistant director of Mineral Resources Development in the U.S. Bureau of Mines. He has been engaged in mineral economics analysis for the past 15 years, following several years in industrial economics fields and in teaching.

In 1947 he taught economics at Kenyon College, and for several years he taught at the Department of Agriculture Graduate School at George Washington University; he is presently teaching at George Washington. He joined the New Jersey Bureau of Research and Statistics in 1948, and he subsequently served as a consultant to the Ohio Department of Highways and, for a year and a half, he was engaged in a special research project for the RAND Corporation. For 15 months during 1960–61, he was the Interior member of the Trade Agreements Committee at the meetings of the General Agreement on Tariffs and Trade in Geneva.

He received the A.B. degree from Kenyon College, Gambier, Ohio, and the Ph.D. degree from Princeton University.

Warren E. Morrison is presently serving as an economist, specializing in energy, in the Division of Economic Analysis, Bureau of Mines, United States Department of the Interior. He is in charge of conducting studies investigating the energy economy, with emphasis on energy flows, interfuel competition, and projections of future requirements and supply.

Between 1948 and 1953 he served the U.S. Department of State as a foreign affairs analysist and intelligence research specialist in the field of foreign minerals economics. He has been with the Department of the Interior since 1953 and, for the past three years, he has been the author of the annual review of the mineral-fuel industries in volume II of the Department of the Interior *Minerals Yearbook*.

Mr. Morrison was graduated from Georgetown University with a B.S. degree. He completed a year of graduate work in economics at the Georgetown University Graduate School, and he holds a master's degree in business administration from George Washington University.

Human enhancement through evolutionary technology (page 87)

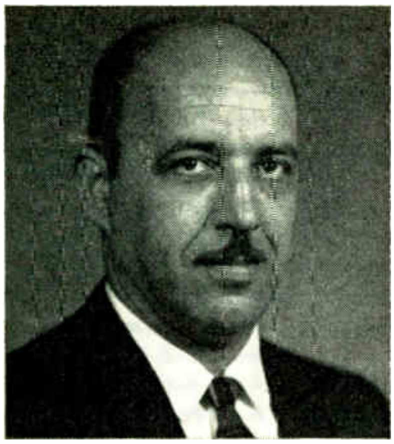
Warren M. Brodey (right) is on the staff of the Division of Sponsored Research, Massachusetts Institute of Technology, and he is also a research affiliate, Research Laboratory of Electronics, M.I.T. He joined the M.I.T. staff in 1964 as a member of the Cognitive Information Processing Group, and he is presently director of the M.I.T. Science Camp. In 1965–1966 he was a consultant to the NASA Computer Laboratories.

He received a medical degree from the University of Toronto in 1947, and then interned and trained in psychiatry and child psychiatry in Boston. He also served as assistant director of the Worcester Youth Center prior to joining the Clinical Center of the National Institutes of Health in 1956. For the next three years he was engaged in a research project involving the study of communication systems used within families. This work contributed to the development of family therapy, a now widely used psychiatric method.

Dr. Brodey, before joining M.I.T., was assistant clinical professor at Georgetown University Medical School and a member of the faculty of the Washington School of Psychiatry. He is a cofounder of the Pilot School for Blind Children, a charter member of the American Society for Cybernetics, and a member of the American Psychiatric Society, the American Ortho Psychiatric Society, AAAS, and the American Academy of Child Psychiatry.

Nilo Lindgren. A biographical sketch of Mr. Lindgren (left) appears on page 196 of the March 1965 issue.

Spectral dependence of deep-space communications capability (page 98)



John Dimeff is chief of the Instrumentation Division at the National Aeronautics and Space Administration's Ames Research Center, Moffett Field, Calif. He joined the Instrument Development Section of the Laboratory in 1946 and, since that time, he has served on study groups concerned with the Orbiting Astronomical Observatory and the Solar Probes (dealing with measurement of particles and fields in space). He is the author of 16 papers.

Mr. Dimeff was graduated from Harvard University in 1942 and, subsequently, he joined the Vacuum Tube Development Section at the Naval Research Laboratory to work on microwave transmitter tubes. Between 1943 and 1945 he supervised a small group concerned with development of magnetrons and served on the Joint Army–Navy Committee for Magnetrons.

William D. Gunter, Jr. (M) is presently with the Radiations Research Branch of the NASA Ames Research Center, Moffett Field, Calif., where he leads a group of ten scientists engaged in improving methods of measurement in optics and spectroscopy. Areas of activity include flow visualization, pulsed heat flux measurement, laser Doppler velocity detection, thermal imaging, holography, and spectroscopic plasma diagnostics. He is one of the originators of the use of total reflection to increase photocathode sensitivity, and he is working on the further development of this and other optical means of increasing the effective sensitivity of photomultipliers.

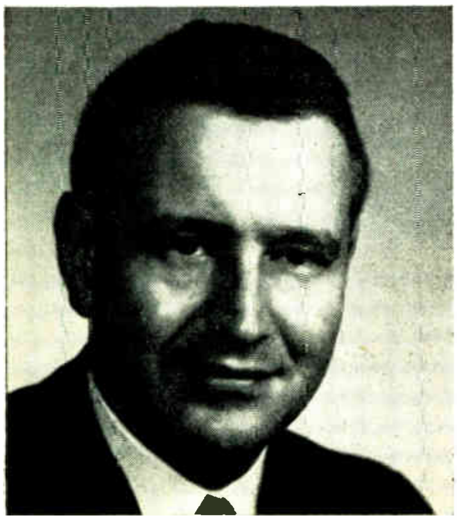
Mr. Gunter received the B.S. and M.S. degrees from Stanford University. He spent the summers of 1956 and 1958 at the Ames Research Center, and he returned there in 1960.

Ronald J. Hruby (M), presently a member of the staff of the NASA Ames Research Center, is engaged in work on free-flight telemetry in wind tunnels, microwave systems for interior ballistics, tape recorder applications for high-speed transients, communication properties of solar space, and the application of microwave methods to surface crack detection in metals.

He holds B.S. and M.S. degrees in electrical engineering from the California Institute of Technology, a degree of engineer in electrical engineering from the University of Southern California, and the M.S. degree in physics from San Jose State College.

Prior to joining the Ames Center, Mr. Hruby was with the Douglas Aircraft Company and, subsequently, in the Norair and Nortronics Divisions of the Northrup Corporation.

Wanted: a physically possible theory of physics (page 105)



Rolf Landauer (SM) is assistant director of research at the International Business Machines Corporation Thomas J. Watson Research Center, Yorktown Heights, N.Y. His primary personal scientific interests have been in the physics of computing devices, transport theory, ferroelectricity, and nonlinear electromagnetic wave propagation. His most recent work points out the possibility of optical shock formation in the presence of intense light beams.

He received the B.S. degree from Harvard University in 1945, at age 18, and, after service in the Navy, he obtained the Ph.D. degree from Harvard in 1950. He was a member of the staff of the Lewis Laboratory, NACA (now NASA), Cleveland, Ohio, for two years, and he then joined IBM, Poughkeepsie, to work on semiconductors. He has since held a variety of research and administrative positions in the area of solid-state physics and its relationship to computers. He has initiated a number of research programs, including the work leading to the discovery of the injection laser and IBM's work on large-scale integration and insulated-gate field-effect transistors. He is a Fellow of the American Physical Society and a member of the National Academy of Sciences.

Electron devices in science and technology

The many achievements in electron devices, particularly since the turn of the century, can be used as a yardstick to forecast trends in this rapidly expanding field

R. Kompfner *Bell Telephone Laboratories, Inc.*

Whatever one may think about progress in the affairs of mankind, it cannot be denied that great things have happened in the recent past in science and technology, much of it a direct consequence of the invention and development of many different kinds of electron devices. This article speculates on future trends and developments, and the engineer's probable role.

Some of you may remember that the IRE celebrated its 50th year of existence in May 1962. On that occasion the PROCEEDINGS published a jubilee issue, which contained a number of very useful and competent reviews of the state of the art by experts in many fields. It also contained a section entitled "Communications and Electronics—2012 A.D.: A Predictive Symposium by Fellows of the IRE."

I was one of those who were asked to contribute to this section. This was a great and appreciated honor, but I found that any ideas that came to me in trying to foresee what our world would be like in 2012 were so feeble, such obvious extensions of our present-day world, such trivial projections of already existing trends that, in the end, I declined the honor with regrets.

Now, just five years later, I am not sorry that I did. From reading these forecasts now, it is clear that engineers, however eminent they may be in their many fields, are not science fiction writers. They are not in a class with Jules Verne, H. G. Wells, and Jonathan Swift. Obviously much thought had gone into this "Symposium" and there were many ingenious ideas. Still, the overall impression—on me, at any rate—was unconvincing, and I came to the conclusion that engineers are not particularly good at forecasting the future.

Engineering, however, more than any other profession, appears to shape the future. I say this because of what engineers have accomplished in the past. It is tempting to make a simple extrapolation: they will keep on shaping the future. Such forecasting seems to be pretty safe. But is it really?

It is this problem to which I shall address myself. In order to avoid floundering in generalities, I shall restrict the field of inquiry. Naturally, science and technology, one of the "two cultures" of C. P. Snow, is my frame of reference. Within it I shall, however, confine my attention to "electron devices," a small but crucial subfield of electrical and electronics engineering. I shall look at its past, consider the present, and then we shall see what can be said about the future. (It seems clear that the better the understanding of the past the more meaningful will be the appraisal of the future.) If we then should come to a conclusion about the future of electron devices, we may, or may not, apply it to technology in general.

Revised text of a talk presented at the IEEE Electron Devices Meeting, Washington, D.C., Oct. 26–28, 1966.

Electron devices in the past

Historically, I suppose, the term "electron devices" goes back to the time when radio engineers were concerned with antennas, with propagation, with circuits, and with components that made it possible for radio to work—namely, the vacuum tubes, the devices in which the electrons were moving around freely. These were clearly so different from other components and clearly so important that a special, although broadly applicable, name was invented: *electron devices*. For my purpose here I propose to define an electron device even more broadly, as a man-made construction in which electrons play a crucial part by virtue of their charge, mass, or spin.

A device may be invented, designed, or developed for a variety of purposes. It may be intended to assist in making discoveries. It may simply serve a useful function, such as amplifying a weak signal. It may be used to generate radiation. It may be built just out of curiosity, so that its behavior can be studied, as a means of studying nature.

With all this in mind I claim that the Geissler discharge tube (actually invented by Plücker in 1858) was the first electron device: a partially evacuated glass tube through which a current can be made to pass. That this current is made up of electrons and ions was, of course, not known at first, but the device was clearly an intriguing one. It demonstrated the power of science in that it combined the science, or art, of pumping air out of a vessel with the new electrical science of the induction coil, to produce an impressive display of glowing color. It was a curiosity—and it provoked curiosity, the desire to discover and learn. Soon someone (I don't know who) discovered that a magnet brought near the discharge tube affected the discharge, and I believe it was Plücker who discovered, after getting a better vacuum than anybody before him, that the envelope could be made to fluoresce and that this fluorescence was due to the impact of rays coming from the cathode—which were called *cathode rays* by Goldstein in 1876.

In 1895 Roentgen was experimenting with such a tube when he discovered X rays. I cannot resist repeating what has been pointed out many times before: that many great discoveries are not planned, or scheduled. Nor was Roentgen's discovery a lucky accident, in the sense that anybody playing with the discharge apparatus would eventually have made the same discovery.* It needed a Roentgen to study this particular combination of apparatus and phenomenon, *and* his perceptiveness *and* his audacity in postulating an invisible radiation penetrating solid bodies other than glass *and* his skill in making clean, comprehensive, and decisive experiments.

Here is an electron device that surely has had an immense impact on our life and civilization. Its most immediate impact, of course, has been on medicine. (Less than three months after their discovery, X rays were put to use in a hospital in Vienna.) With the help of X rays, the structure of the atoms of all the elements has been determined; atomicity itself, the structures of crystals including those of some very important organic compounds such as DNA and RNA—these are only a few of the more recent triumphs.

*The story is told of a laboratory assistant who reported to the Professor of Experimental Philosophy at the Clarendon Laboratory, Oxford, that the photographic plates stored near a Crookes' tube appeared to be darkened by it and was told by the professor to store them elsewhere.

Within a year of Roentgen's discovery, J. J. Thomson had determined that cathode rays are negatively charged particles of a certain charge-to-mass ratio, that they could be accelerated by electric fields and deflected by magnetic fields. This, some people believe, led to the invention of the cathode-ray-tube oscillograph associated with the name of Braun. Several years earlier Heinrich Hertz and Hallwacks had discovered the photoelectric effect; but I think that Elster and Geitel, in the 1920s, found that photoelectric emission took place also in a vacuum. They, presumably, invented the photocell. Edison discovered thermionic emission from hot filaments in his lamp, and thereupon J. A. Fleming in England invented in 1905 what we now know as the vacuum-diode rectifier, which he called a "valve."

I never cease to wonder at the fact that more fuss is not made about the invention, in 1907, of the audion or triode by De Forest. Everybody "knows" that Marconi invented radio, Edison the phonograph, the Wright Brothers the aeroplane, but relatively few people know of De Forest, whose invention really has transformed our civilization. Such a simple thing: to put a grid between the filament-cathode and the plate. And such a momentous result!

Try to picture modern communications, including radio and television; physical sciences, such as nuclear physics, physical chemistry, solid-state physics; life sciences, such as biology and neurophysiology; or defense and space technology, navigation and guidance, and many other fields of human activity—without electronic amplification. (This is now done by transistors, of course.)

You undoubtedly will have noted that I am trying to show just how important electron devices have been; not only to electronics and engineering, but also to science (pure as well as applied) and to human life in all its manifestations. All this, of course, is in support of my thesis that engineers have helped to shape the future.

Notable developments in electron devices

At this point I should like to list a few more of the important discoveries and inventions in electron devices, starting with the period around 1900:

J. J. Thomson and Aston: Positive-ray e/m measurement and mass spectrography
Rutherford and Geiger: Geiger counter

There seems to be a gap of some 20 years during which no electron devices of comparable importance were invented, perhaps as a consequence of World War I. In the 1920s came

A. W. Hull, Barkhausen, Kurtz: Magnetron oscillator and triode transit-time oscillator
Zworykin: Iconoscope
Busch and Gabor: Magnetic electron lens
Davisson, Germer, G. P. Thomson: Electron diffraction tube (which led to the discovery of the wave nature of matter)
Langmuir and Hull: Thyratron
Schottky and others: Multigrid tubes (tetrodes, pentodes)

Later on, in the 1930s, came

Cockcroft, Walton, Van de Graaff: High-energy particle accelerators
Lawrence: Cyclotron
Heil and Brüche: Velocity modulation principle

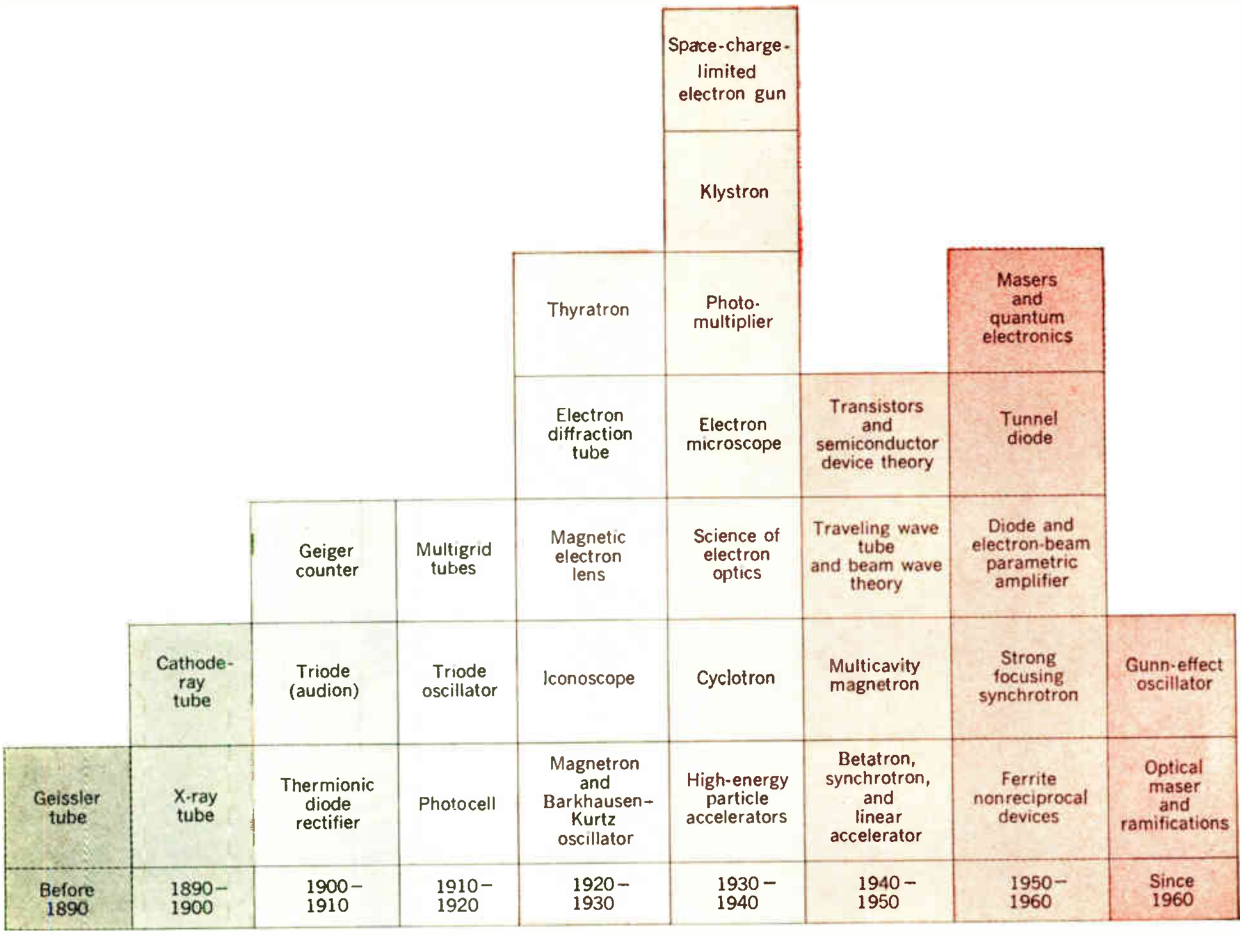


FIGURE 1. Electron-device milestones.

Hahn and Varian brothers: Klystron
Zworykin, Morton, Malter: Photomultiplier
Knoll and Ruska: Electron microscope
Several teams, mostly in Germany: Electron optics

This period marked the beginning of a science of electron devices, which started as the dynamics of particles in conservative fields, and later also in nonstationary fields, including those due to the charged particles themselves. Science by now has come to the aid of electron devices (as a small repayment for the aid electron devices have given to science).

The 1940s saw the following developments:

Pierce: Space-charge-limited electron gun
Kerst: Betatron
W. W. Hansen: Linear accelerator
Oliphant, Veksler, McMillan: Synchrotron
Randall, Boot, Sayers, Millman: Multicavity magnetron
Haeff, Kompfner, Pierce:* The traveling-wave tube and electron beam and wave theory

* The writer has struggled with the problem of including his own name in the list for some time. It eventually occurred to him that noninclusion would be even more ridiculous than inclusion.

Bardeen, Brattain, Shockley: The transistor and semiconductor-device theory

Developments in the 1950s included

Hogan: Nonreciprocal ferrite devices
Uhlir and Suhl: Varactor diode and parametric amplification
Esaki: Tunnel diode
Livingston and Christophilos: Strong focusing synchrotron
Townes, Weber, Basov, Prokhorov: Maser (quantum electronics)
Adler: Electron-beam parametric amplifier
Buck: Kryotron

And now in the 1960s:

Townes, Schawlow, Maiman, Javan: Optical maser, and all its ramifications
Franken: Nonlinear optics
Gunn and Read: Gunn oscillator and transit-time effects in semiconductors

The foregoing list is clearly far from complete, nor can I expect to obtain agreement on its general validity. It comprises what I personally consider to be electron-device milestones, identified as far as possible by the invention, and the inventors or major contributors.

Many of the inventions have led to extensive further developments and more inventions; some have led to major discoveries and developments in physics and other sciences. I had to cut off somewhere, and I tried to exercise reasonable judgment in doing so.

Let us now examine the result, which is summed up in Fig. 1. When I look at this chart, I cannot help feeling proud to have been associated with a branch of human activity of such incredible breadth and depth, ingeniousness and creativity, and of such usefulness to so many other important spheres of endeavor. Those who work with electron devices have indeed been close to "where the action is" for a long time.

Is it possible to draw from the chart any conclusions that will help us to see what the future may bring? Not yet! Before attempting to do this we need to acquire some perspective, so that we can see electron devices in the context of technology, technology in the context of science and technology, and finally science and technology in the context of all human activity.

Peaks and troughs

Looking at the chart of "milestones" we note something like a peak. Although this peak may just possibly represent merely a statistical fluctuation due to the small numbers of "events," I shall treat it as real and important. We know that there are peaks and troughs in all kinds of human affairs. There are such peaks in the arts, and presumably also in the sciences.

Consider, for instance, music in Vienna between 1790 and 1820. The musical giants of those days included Haydn, Mozart, Beethoven, and Schubert. Where else, or whenever, has there been such a concentration of musical genius within such a short time span or in such a small space?

Or let us take theoretical physics between 1900 and 1930—a period that saw such "greats" as Lorentz, Planck, Einstein, Bohr, De Broglie, Heisenberg, Schroedinger, Dirac, Pauli, Sommerfeld, and Debye. Here again was a peak in time and space.

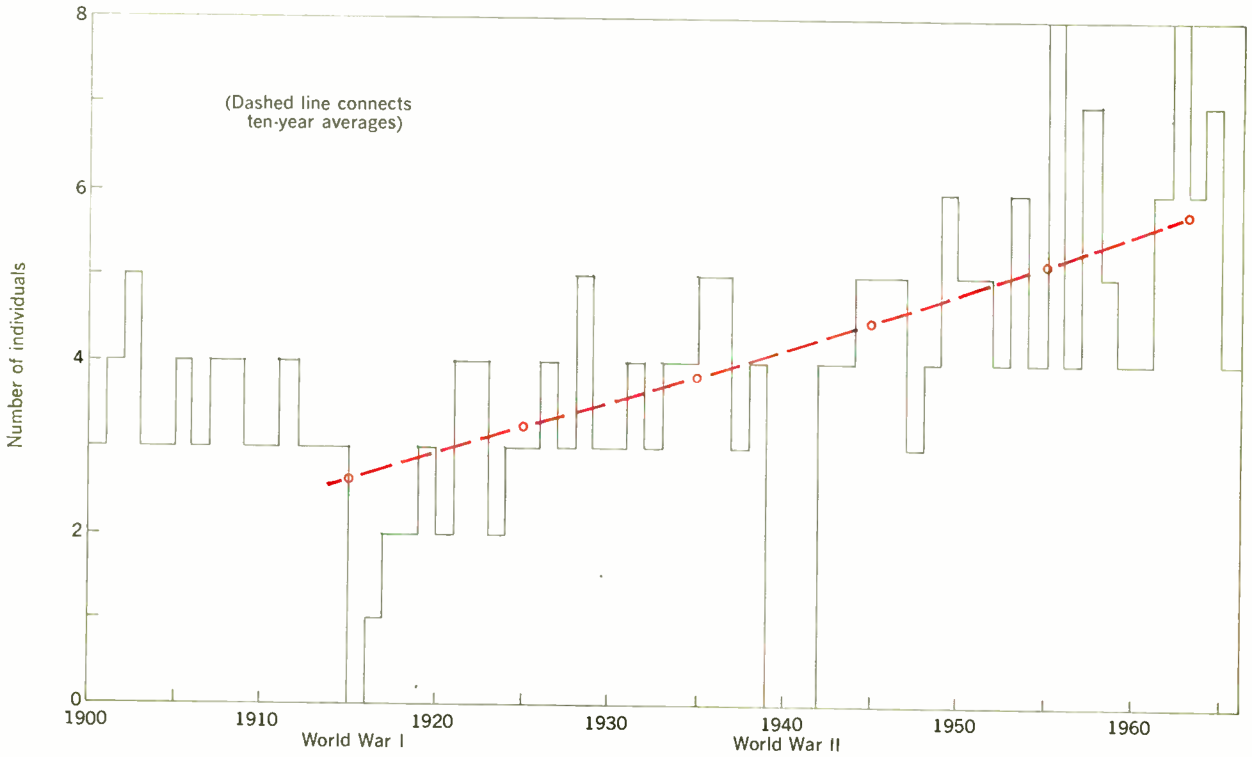
Thus it can be seen that there is nothing new in this phenomenon of wave crests and troughs. However, how does this phenomenon fit in with other things we know?

It has been said that "The number of scientists alive today is equal to 90 percent of all the scientists and research workers who have existed since the beginning of history."

This fact is a direct consequence of the exponential increase in the number of scientists during the last few hundred years with a doubling time of 15 years; however, it is not easily reconciled with the impression of the peak in theoretical physics from 1900 to 1930 described earlier. It may well be held that this peak is only a subjective illusion, that any other 30-year period would exhibit an appropriate and adequate number of eminent physicists. An uncritical application of the "90 percent" statement would indeed imply not only that at least 90 percent of those mentioned should be alive now, but also that 90 percent of the scientists alive now should be of the stature of Galileo, Kepler, Newton, Faraday, Maxwell, and so on.

That this is not the case surely does not require proof. And it leads to an important insight: the exponential increase in the number of scientists, which can be traced back for at least 250 years, does *not* imply a similar rate of increase of eminent scientists.

FIGURE 2. Number of individuals who received Nobel Prizes annually in physics, chemistry, and medicine-biology.



The Nobel Prizes

What *is* the rate of increase of *eminent* scientists? To answer this question is difficult because it depends on subjective judgments of just how eminent a scientist may be. There is, however, an institution that has been making these judgments for quite some time: the Nobel Prize Committees. Over the last 66 years Nobel awards have been given, by and large, to the most deserving and clearly outstanding candidates, and the international scientific community has accepted these judgments.

Looking at the number of individuals receiving awards annually in the disciplines of physics, chemistry, and medicine–biology since 1901* we note that there were years when prizes were not awarded, either because of a world war, or because there was no suitable candidate. We also note that the tendency for sharing awards seems to increase with time. Thus it is possible to obtain a rate at which eminent scientists are recognized, in spite of the fact that each year three prizes at most are awarded. From Fig. 2 we can observe that the average annual number of awards doubles approximately every 45 years. On this basis, admittedly somewhat rough, we should expect a progressive dilution of eminence among scientists, and therefore the relative proportion of scientists of Nobel stature will shrink by one half every 22 years (which confirms what I have suspected).†

One may now ask: What else doubles every 45 years or so? The answer is not too surprising: the human race. Thus we have at last come around to a plausible hypothesis: The fraction of humanity represented by men with outstanding talents and creative genius, with the gift of pushing into new fields and capable of having entirely new thoughts, is constant and independent of time. Those sciences identified by the Nobel Prizes appear to have had just about their fair share of those men.

Let us now return to the phenomenon we observed earlier, the apparent peak in "electron device" activity in the 1930s. There is something remarkable here: Whereas science and technology as a whole double every 15 years, one of the most important branches of science and technology not only has stopped growing, but seems to be actually shrinking. One may wonder why this is so. Perhaps there is little left to be invented, which is as if somebody had said, in 1820, that there was no music left to be composed after Haydn, Mozart, Beethoven, and Schubert.

A more plausible explanation is that electron-device activity has not had a fair share of the creative fraction of humanity for some time, and that its share is still rapidly diminishing. This is the clear inference to be drawn from the "peaking" phenomenon.

Since the overall number of individuals with extraordinary gifts is increasing, there must be peaks building up in other fields of science and technology. One is reminded of waves in the ocean, which grow and shrink in some unpredictable manner even though the molecules of the top layer remain essentially the same. An extra large wave comes about by the accidental superposition of more than the usual number of waves, but its very size ensures that it vanishes all the sooner and is replaced by a correspondingly low trough.

Contemporary art seems to have hit such a trough, and one wonders where the creatively gifted individuals are and what they might be doing now—the type of individuals who, in other times, produced the art of the Renaissance and the music of the Baroque. I have a suspicion that they are now forming part of the scientific and technological wave that comprises physics, chemistry, biophysics and biochemistry, astronomy and mathematics, communication and computer science, and space and nuclear engineering.

Returning to electron devices, there is another aspect to consider when one ponders the information contained in Fig. 1; that is, the earlier electron-device milestones represent contributions by engineers as well as by scientists—engineers with electrical training and scientists with training in physics. The achievements in the last decades, however, are almost entirely those of physicists.

If we accept the thesis that the fraction of superbly gifted individuals remains constant in time, we are forced to conclude that a rapidly shrinking fraction of them contribute to the science and technology of electron devices, and an even smaller fraction of them are trained in electrical engineering.

This is a very serious matter to us electrical and electronics engineers. I am not concerned about the number of members of the Electron Devices Group. That number, I am sure, is growing. I am concerned about our *share* of the significant contributions to science and technology, *and that seems to be shrinking.*

I am afraid what we see here is only a small part of something much bigger. The bigger thing is that *technology* (or engineering) is slipping with respect to science.

I could document this statement with more statistics and curves, but in the interest of saving time, let me merely point to the number of Nobel Prize awards for engineering contributions as compared with those for scientific contribution—and this in spite of the fact that Alfred Nobel's will reads: ". . . to those who, during the preceding year, shall have conferred the greatest benefit on mankind . . . one part to the person who shall have made the most important discovery or *invention* within the field of physics; one part to the person who shall have made the most important chemical discovery or improvement . . ."

We can count the number of engineering contributions that were deemed worthy of the Nobel Prize on the fingers of one hand! We may quarrel with the way this came about, but it is a fact nevertheless.‡

* I have made no distinction between awards given for a particular achievement and shared among a number of contributors, and a divided award.

† After doing this little piece of "research" on my own, I came across a book, *Little Science—Big Science*, by D. J. de Solla Price, that does a far more thorough and imaginative job of quantifying science and scientists than I could ever do. I highly recommend it to anybody interested in what really goes on, and has been going on, in the development of science. I was happy to find that nothing I am saying is in essential contradiction with Price's discoveries.

‡ People whose opinion I respect have indeed quarreled with me on this issue. It would take altogether too much time and space to air my views and prejudices here. The story of the establishment of the Nobel Prize makes fascinating reading, as reported in the book, *Nobel, the Man and His Prizes*, by H. Schück *et al.* (Edited by the Nobel Foundation, University of Oklahoma Press, Norman, Okla., 1951.) A story of how the Nobel Prize came to be accepted by the international scientific community; how and why the direction and impact gradually changed; how the award managed to live with diplomatic, political, and public pressures and influences, and to thrive, would make an equally fascinating book. I hope it will be written during my lifetime.

It has not always been like that. When the Royal Society was founded, in 1660, its charter read "... to study all things mathematical, philosophical and mechanical ... and to promote the improvement of all useful arts, manufactures, mechanical practices, engines, and inventions." ("Philosophical" meant physical sciences in those days.) The present membership of the Royal Society no longer reflects these intentions (see box).

Science has become more and more respectable; the purer, the more respectable. But we must admit that it has become even more exciting, more inspiring, more promising of greater things to come.

Since October 1966, when the talk on which this article is based was given, corrective action has been initiated, as can be seen from this portion of an address given by Prof. P. M. S. Blackett to the Royal Society on November 30, 1966:

"The Royal Society has, in the past, included in the fellowship such outstanding engineers as Smeaton Rennie, James Watt, Brunel (father and son), R. Stephenson, Siemens, Parsons, S. D. de Ferranti and Sir William Stanier, to mention only a few. It is my personal view, however, that in recent decades the Society has been somewhat remiss in not recognizing more engineers and applied scientists by admission to the fellowship. I gain the impression that the level of ability, originality and eminence required of an engineering designer, for example, to be admitted to the fellowship has been disproportionately higher than that required of a research scientist. I feel that the imbalance between these two levels has been detrimental to the Society and to Britain as a whole.

"The situation in this respect, however, is changing. For the past three years this problem of giving adequate recognition to engineers and technologists has been seriously discussed within the Society. One outcome was the raising in 1964 of the number of candidates elected each year from twenty-five to thirty-two, with the explicit object of using some of these seven additional places for applied scientists and engineers."

Here lies a great danger: a flourishing science feeds on flourishing technology and vice versa. If one of the two withers, the other one will surely also die eventually. If science draws the best and brightest young spirits into its orbit and what is left goes into engineering, in the end both science and engineering will be doomed.

It is my belief that the Nobel Prizes have served not only as yardsticks against which achievements may be measured; *they have also directly affected what they measured* by attracting the bright, young, impressionable spirits to the very fields in which the prizes were awarded. They are a link in a positive feedback circuit, in which instability can happen, if indeed it has not already happened.

Recognition of engineering achievements

It is unpleasant to complain. It is also useless to complain. Results are best obtained by positive action. If at this late hour it might prove difficult to persuade the Swedish Academy of Sciences to adjust their scale of values to be more responsive to Alfred Nobel's will, is it not possible to find another man with vision, and money, to found prizes for engineering achievements—prizes that could become comparable in stature and impact to the Nobel Prizes? To show what I mean, consider these men, now living, as representative examples of possible candidates:

- *E. Ruska*, for the invention of the electron microscope
- *V. Zworykin*, for the invention of the iconoscope
- *F. Whittle*, for the invention of the jet engine
- *D. Gabor*, for the invention of holography
- *C. E. Shannon*, for his contribution to information theory

Such prizes not only would be well-merited rewards for important achievements; they would serve as yardsticks against which to measure other achievements; they would help to educate the general public and enhance its ability to discriminate between what is great and what is mediocre both in science and in technology; and they would be an inspiration for the young and aspiring ones. All of these goals have been achieved by the Nobel Prizes for science.

Another positive action could be taken in the field of education, where physics has made great efforts in recent years to make itself as fascinating as possible to teachers as well as to pupils and where it needs to be shown that science and engineering together can be even more fascinating, that the combination has a deeper meaning for mankind and a more profound impact.

At the present time, when we are witnessing the conquest of space by men (incidentally, mostly engineers and not scientists); when we are about to see the "fourth state of matter"—*plasma*—play a part in bringing about thermonuclear energy conversion; when we are close to an understanding of the phenomena of superconductivity and superfluidity and even closer to applying such understanding; when we are in the middle of the gigantic revolution in information processing and automatic control brought about by the advent of the digital computer (another engineering achievement); is this the time to worry about the decline of technology in general, and electron devices in particular?

I say yes—unless we see to it that we are in the middle of all this, making our rightful contributions.

It should be obvious to the reader that this article embodies the ideas and views of the author only. Nevertheless, I should like to acknowledge the helpful criticisms of a number of people, including C. C. Cutler, E. E. David, and S. J. Buchsbaum, without implicating them in any way if possible. Special thanks are due to Prof. C. Süsskind, who has rectified some of my historical "facts."

Numerical solution of electromagnetic problems

Using integral equations, the high-speed digital computer provides accurate solutions to complex electromagnetic problems that hitherto have been solvable only by experimental methods

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Modern high-speed digital computers have made possible the solution, by theoretical–numerical techniques, of many problems in electromagnetics that have traditionally been solvable only by experimental methods. Formulated in terms of integral equations, the techniques described yield answers, with an accuracy and completeness unobtainable by experimental methods, in a small fraction of the time and at much less cost than by the experimental approach. Computer programs utilizing these techniques have been developed in the areas of radiation and scattering from arbitrary wire-antenna structures, bodies of revolution, and cylindrical bodies of arbitrary cross section.

It has not been many years since the fastest calculating machine available to engineers and scientists for numerical computations was an electrical desk calculator. This situation has changed dramatically; the development of high-speed electronic computers has made possible computations at speeds more than a million times that of a desk calculator. Thus the time it takes to multiply two 10-digit numbers is less than one microsecond on the world's fastest computer, the CDC-6600. It can hardly be a surprise to anyone that this development has had and will continue to have a tremendous impact on many areas of technology and engineering. The modern digital computer has enabled us to solve many technical problems faster and at less cost than before. Of even greater significance is the fact that digital computers have enabled us to undertake problems that could never have been attempted without them. The real-time calculation of space-vehicle trajectories is one example; the elaborate numerical processing involved in reconstructing photographs of maximum quality relayed from Mars by Mariner IV is another.

It is probably less well appreciated, however, that the computer also permits the invasion, by theoretical techniques, of problem areas that traditionally have been the exclusive domain of experimental methods. One example is the area of electromagnetics. Although there are many electromagnetic problems for which the theoretical–numerical techniques described here cannot be expected to compete economically with experimental methods, at least not at the present time, there are also many problems hitherto amenable only to experimental attack that today can be solved by theoretical–numerical techniques faster, at less cost, with greater accuracy, and with a completeness altogether unobtainable by experimental methods. It is significant that the properties of an antenna configuration, for example, can be evaluated more economically by computer techniques than by experimental methods; however, it is perhaps even more important that the computer can also be programmed to change the antenna configuration in a systematic way to find a structure that is optimum in certain respects. It is not at all unrealistic to expect that an optimization that might take several weeks if done experimentally can be done within ten minutes by computer.

Although the theoretical–numerical techniques can be expected to make many experiments superfluous, the computer programs using these techniques could hardly be developed without the experiments because the experiments are very important for checking the validity of the computer programs developed.

Differential equations

To understand better the new ingredient that computers have added to the theoretical possibilities for treating practical electromagnetic problems, it is desirable to review briefly the theoretical techniques available for the treatment of such problems. For almost two centuries the most useful method has been the method of separation of variables, invented by Fourier, which resulted in the discovery of the Fourier series. This method describes the boundary-value problem in terms of a partial differential equation. If the boundary surfaces in the problem, the surfaces of a waveguide for example, coincide with the natural surfaces of the coordinate system, solutions for problems are readily obtained in terms of the so-called eigenfunction solutions of the differential equation. This method, sometimes called the harmonic series method, has been responsible for a great many important results. For example, all information concerning the common waveguide and resonator modes in rectangular and circular waveguides have been obtained by use of this technique.[1]

Where the shape of the structure does not coincide with coordinate surfaces—and in most practical engineering problems this is unfortunately the case—the harmonic series method is of little value. Odd-shaped waveguides or irregularities or obstructions in normal waveguides—in fact, almost any nonideal or practical situation including virtually all radiation and antenna problems—can be treated only approximately. Even such idealized problems as slender cylindrical dipole or biconical antennas are treated only approximately by analytical methods based on differential equations.

Integral equations

Differential equations, such as Laplace's, Maxwell's, and the wave equation, are one form in which problems in mathematical physics and engineering can be stated. An alternate form is the integral equation, but heretofore the integral equation statement of a problem has not been very helpful because no one has been able to solve such equations for cases of practical interest.

A significant development occurred when it became possible to use integral equations to develop variational expressions of such important physical quantities as the equivalent reactance of waveguide discontinuities, the impedance of simple antennas, the resonant frequency of cavity resonators, and electrostatic capacitance. This variational principle as developed by Schwinger was an important step forward because it was not limited to simple geometries (spherical, circular, cylindrical, or plane surfaces) as were differential equation methods, but it would permit solutions for fairly general geometries. One disadvantage of the variational principle is that it is difficult to estimate the error, which depends on the choice of a certain trial function and may not always be small. The importance of Schwinger's variational principle has diminished somewhat because the availability of high-speed electronic computers today has made possible the direct solution of integral equations from which the variational expressions were developed.

To see what we mean by an integral equation, consider the following expression, which gives the electrostatic potential due to a distribution of charge, $q(\mathbf{r})$

$$V(\mathbf{r}') = \int \frac{q(\mathbf{r})}{4\pi\epsilon_0 R(\mathbf{r}, \mathbf{r}')}\, dv \tag{1}$$

This basic equation says that we can find the potential V at a position in space (indicated by the radius vector $\mathbf{r}'$) by dividing all the charge in space into the equivalent of a very large number of infinitesimal point charges and summing (integrating) their individual contributions. The magnitude of the individual point charge at location $\mathbf{r}$ is $q(\mathbf{r})\, dv$, and its distance from point $\mathbf{r}'$ at which the potential is being calculated is $R(\mathbf{r}, \mathbf{r}')$ (the distance is a function of both $\mathbf{r}'$, the location at which the potential is being calculated, and $\mathbf{r}$, the location of the point charge whose contribution to the potential is being considered). This equation is given in even the most elementary books dealing with electric fields. It is usually presented with the idea that if we know the distribution of charge $q(\mathbf{r})$, we can then determine the potential at any desired point in space by performing the indicated integration.

In most cases of engineering interest, however, we know very little about the charge distribution, but may have some very important information concerning the potential. We do not know what the potential is everywhere in space, but we do know that at all points on the surface of a conductor the potential has a constant value. Consider the umbrella antenna illustrated in Fig. 1, for example; if one volt is applied to the antenna we know that charge will flow onto it, but not how much charge or where it will flow. If we knew, we could say a great deal about how the antenna would perform as a low-frequency broadcast antenna. We could calculate its effective height, its capacitance, its radiation resistance, its bandwidth, and even the electric fields about the individual conductors composing the antenna.

Keeping the antenna in mind, let us now return to Eq. (1). Because we know the voltage to the antenna, (1) is an integral equation when applied to points on the surfaces of the conductors making up the antenna. This term is used because the unknown quantity in the problem, the charge distribution on the antenna, is under the

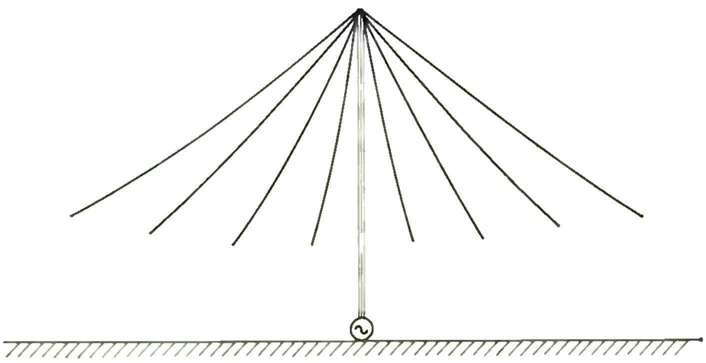
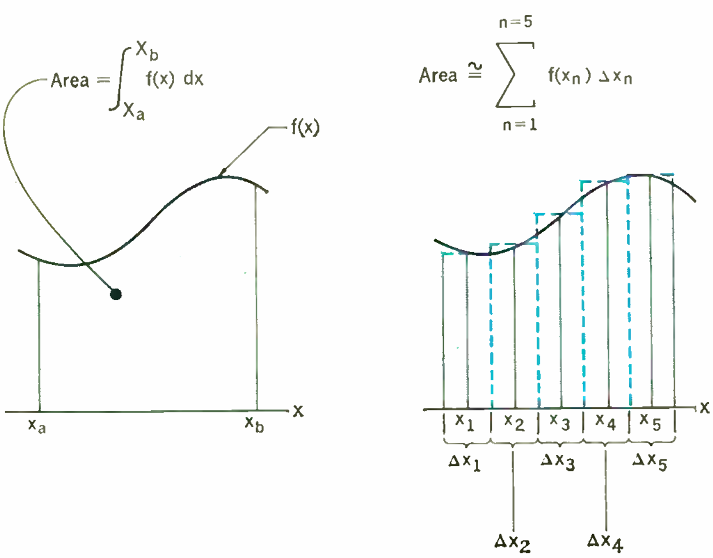


FIGURE 1. Low-frequency umbrella antenna.

FIGURE 2. Approximating an integral by a finite sum.



integral sign. If the integration is performed for each point on the antenna, it must lead to the correct value of potential. Although at any particular point there are many charge distributions that will give the correct potential, only one distribution yields the correct value at all points. The distribution capable of producing this result is the solution of the integral equation.

In times past, the matter rested here. It was recognized that there was a distribution of charge that constituted a solution to the equation but no one had any useful ideas on how to go about finding it even for relatively simple configurations of conductors.

To see how computers have altered this situation, let us look again at this equation. It is well known that an integral is the limit of a sum, and that to evaluate an integral numerically, one replaces it by a finite sum of discrete sampled values of the function being integrated, each of which is multiplied by a weighting factor that includes, among other things, the size of the interval between sampling points (see Fig. 2). The accuracy with which the evaluation is made depends upon the number of terms in the sum and how clever one is in choosing a numerical integration method; Simpson's rule, for example, generally yields a more accurate answer for a given number of terms than does the simpler method, sometimes called the trapezoidal rule. Suppose we decide to evaluate the integral of (1) by replacing it with a finite sum. This corresponds roughly to breaking up the entire antenna into N sections and calculating the potential at the point in question by considering the charge on a segment at some distance from our point to be concentrated at the centroid of the segment. If we are evaluating the potential at the center of the pth segment, then the integral of (1) becomes

$$V(\mathbf{r}_p) = A_{p1}\frac{q(\mathbf{r}_1)\Delta_1}{R_{p1}} + A_{p2}\frac{q(\mathbf{r}_2)\Delta_2}{R_{p2}} + \ldots \qquad (2)$$

or, more generally,

$$V(\mathbf{r}_p) = \sum_{n=1}^{N} A_{pn}\frac{q(\mathbf{r}_n)\Delta_n}{R_{pn}}$$

The coefficients A_{pn} now include the constants of the equation in addition to any weighting factors associated with the numerical integration scheme. R_{pn} is the distance from the pth point, where the potential is being calculated, to the center of nth point, where the charge is located.

We remember that for the distribution of charge $q(\mathbf{r})$ to be a solution of the integral equation, the equation had to hold at all points on the surface of the antenna. The analogous condition with respect to the finite sum of (2) is that it has to hold at all N segments into which the antenna is divided. In other words, we will have N equations similar to (2) involving the same N unknowns, $q(\mathbf{r}_n)$. These equations constitute a set of simultaneous linear algebraic equations. The unknowns are the values of charge density at the centers of the N segments into which the antenna was divided; the known quantity is the voltage on the antenna, which we know to have the same value at all N points. The N^2 values of the coefficients $A_{pn}\Delta_n/R_{pn}$ can be calculated without difficulty.

To represent the integral equation adequately may require a set of several hundred simultaneous equations, which for all practical purposes would be insoluble without the aid of a computer. A high-speed computer, however, can calculate all the coefficients and solve the equations in time periods of a few seconds to a few hours, depending upon the complexity of the problem, the accuracy required, and the speed of the computer. As an example, to treat an umbrella antenna having 18 top-load conductors and obtain answers with an accuracy of 0.1 percent requires less than 5 seconds on the Control Data 3800 computer. The much more complicated problem of calculating the radar cross section of a relatively large (electrically) space vehicle. for the entire range of incidence angles and for both polarizations of the incident wave, requires about one-half hour on the CDC-3800.

Besides giving answers more rapidly, more accurately, and generally more economically than can experimental techniques, the computer method described provides information on aspects of the problem that are almost impossible to investigate experimentally. For example, in connection with the umbrella antenna, the computer yields as a matter of course exact information on the distribution of charge and electric field at the tips of the top-load conductors, enabling the designer to decide what diameter he must make the conductors to avoid corona. It can tell him what effect different amounts of catenary sag in the top-load conductors or different numbers of top loads have upon antenna performance.

The umbrella antenna has been discussed in some detail because of its simplicity, and because it is useful in illustrating the general features of the numerical integral equation method. It is also a fairly classic case of a relatively simple practical problem for which no theoretical technique could give useful engineering answers.

The principal reasons for the simplicity of the umbrella antenna problem is that we are dealing with a relatively simple scalar quantity, the static potential. This results in an extremely simple Green's function, which is, in the case of the umbrella antenna, the potential of a point charge $q/R(\mathbf{r}, \mathbf{r}')$.

In more complicated antenna and microwave problems, where the dimensions of the structure are no longer small with respect to a wavelength, we must concern ourselves with radiating waves. In the general case, a source is given that radiates electromagnetic energy in the presence of some boundary surface such as a reflector or an antenna structure The field radiated by the source will induce a current distribution on the boundary surface such that the known boundary conditions for the electromagnetic field there become satisfied. Meeting these boundary conditions leads to the following general integral equation for the induced current distribution $\mathbf{K}$:

$$\left[\mathbf{E}^i(\mathbf{r}') + \int_A \bar{\bar{\Gamma}}(\mathbf{r}, \mathbf{r}')\cdot\mathbf{K}(\mathbf{r})\,da\right]_{\text{tangential}} = B(\mathbf{K}) \qquad (3)$$

where $\bar{\bar{\Gamma}}$ is a dyadic Green's function so defined that the product of $\bar{\bar{\Gamma}}$ and the elementary dipole $\mathbf{K}(\mathbf{r})\,da$ equals the electric-field vector radiated by this elementary dipole. The left-hand side of this equation expresses the tangential electric field at the boundary surface as a sum of the source field and the field produced by the induced current distribution itself. The integral equation says that this tangential electric field must have a value commensurate with the boundary condition B. (B would be zero if the surface were perfectly conducting.)

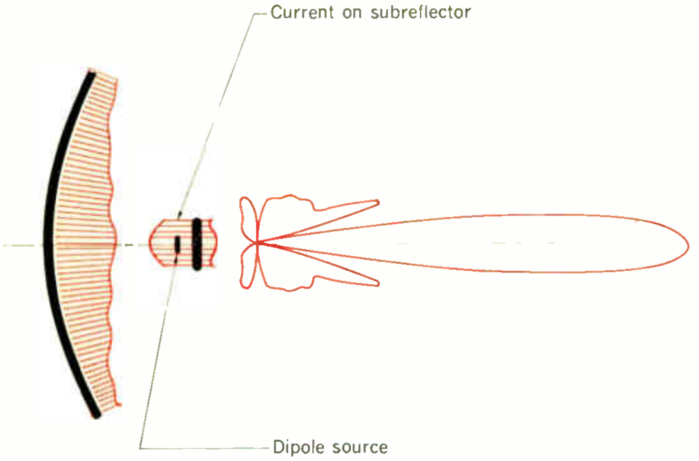


FIGURE 3. Current distribution and radiation pattern of a parabolic cylinder antenna excited by means of a dipole source and a subreflector.

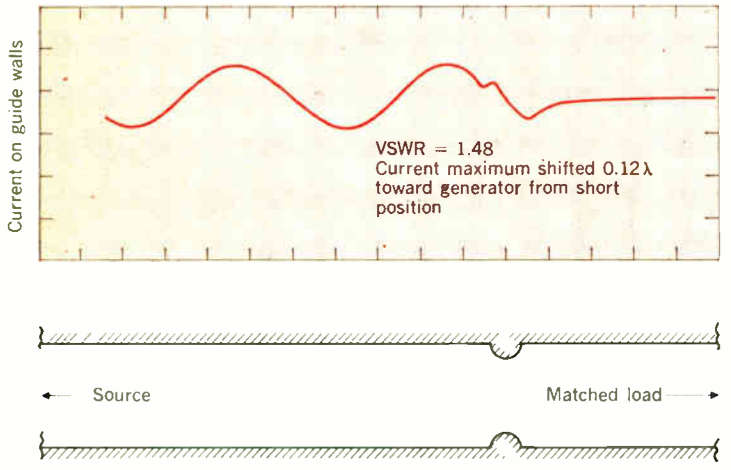
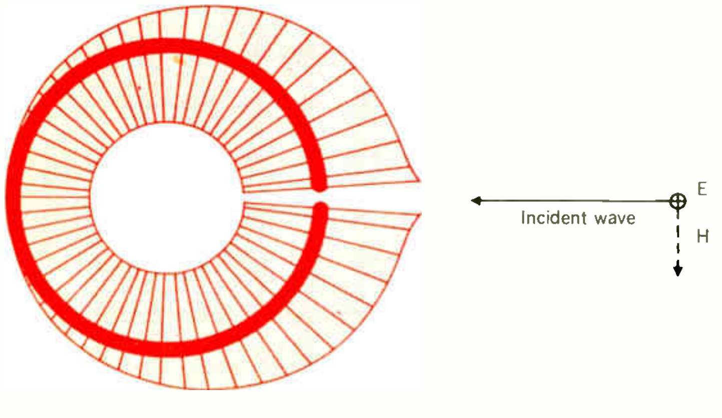


FIGURE 4. The determination of the susceptance of an obstacle in a waveguide.

FIGURE 5. Current distribution on slot-coupled TM_{01} cylindrical resonator excited by a plane wave.



The integral equation (3) can be replaced by a set of simultaneous linear equations just as was done in the case of the umbrella antenna; the computer then solves these equations to yield the current distribution. Once the currents are obtained, the fields they radiate can be be calculated for any point of space by simple numerical integration.

The numerical integral equation method has received considerable attention in recent years. It was used to solve the umbrella antenna problem mentioned above,[2] and has also been applied to the solution of problems of radiation and scattering from other wire structures.[3-7] Other problems solved by this method include scattering in two dimensions[8-11] and in three dimensions.[11-13]

Program for cylindrical reflectors

To give an idea of the power of the numerical integral equation method, we would like to show some numerical results obtained by computer programs that we have developed. The first is a program that calculates the current distribution induced on cylinders of arbitrary cross section by an arbitrary source field. Figure 3 shows an example of the results obtained for a parabolic cylinder antenna illuminated by a vertically polarized line source in front of a subreflector. The conductor cross sections are indicated by the solid black outlines; the current on the front and back surfaces of both reflectors is indicated by the lines drawn perpendicular to the conductor surfaces. The exact pattern of the antenna, including all nulls and minor lobes, is plotted in the polar diagram to the right. Phase information in all parts of the pattern, as well as for all the currents, is also available.

Another example is shown in Fig. 4. In this case we are considering a waveguide terminated by a matched load and an obstacle placed in the guide; the obstacle is a capacitive iris with a semicircular cross section. The distribution of currents on the guide wall is also shown in Fig. 4. From this current distribution it is evident that the reflection from the capacitive iris causes a standing wave on the generator side of the iris. Anyone who has used a slotted line could use the standing-wave ratio and the position of the current maxima relative to the iris to obtain the value of the equivalent susceptance introduced by the iris. This particular case was treated because analytical calculations are possible, as given by Marcuvitz in the *Wave Guide Handbook*. The agreement obtained between Marcuvitz' values and those obtained by the numerical integral equation technique with the digital computer is as close as the curves given by him can be read.

A particularly interesting case, and one that provides an extremely stringent check on the accuracy of the computer program, is illustrated in Fig. 5. Here a plane wave is allowed to fall on a hollow cylinder coupled to space by a very narrow slot; one recognizes this configuration as a cylindrical cavity resonator with a coupling slot. Because the wave is polarized parallel to the axis of the cylinder, the slot shields the interior very well from external fields. At a frequency near the resonant frequency of the cavity, however, one would expect to find a resonant buildup of the interior currents, and by examining the situation at a number of frequencies near resonance, the resonance curve can be established. From the width of the resonance curve, the radiation Q can be determined. It can be shown that a resonance will be predicted by the program only if the solution being given by the computer is quite accurate. Although we haven't the space to detail the reasons for this, it is related to the fact that the resonant distribution of currents inside the cavity can very nearly exist without benefit of an exciting field, plus the fact that if the slot were closed completely no currents would flow on the inside of the cavity.

In this case, because the cavity is so well shielded by the narrow slot, it is possible to calculate its radiation Q quite accurately by approximate analytical methods. The Q calculated in this manner agrees with the Q given by the computer program to within the accuracy of the analytical calculation; both methods agree that the Q is approximately 1.25×10^6. Agreement on a value of Q that is 1000 times smaller than this would have been a very satisfying confirmation of the accuracy. As shown in Fig. 5, the currents of the resonant mode in the cavity are of the same order of magnitude as the external currents and of the magnetic field in the incident wave. At a frequency approximately 0.01 percent lower (one part in 10^4), the currents inside the cavity are nearly 500 times higher; at a frequency 0.5 percent higher they have dropped to less than 3 percent of the value shown.

Program for rotationally symmetric reflectors

Another type of problem, inherently more difficult than any of those discussed so far, is the scattering from three-dimensional bodies. A computer program that solves this problem for bodies of revolution with arbitrary cross section has been developed. The object in this case is to calculate the radar cross section, including the amount of energy returned from the vehicle with polarization orthogonal to the incident polarization. The basic technique is again the same: the currents on the body required to satisfy the boundary condition are first found by numerical solution of the integral equations, and the scattered field is then calculated by suitably integrating over these currents. There are a number of reasons why this type of body is more difficult than the previously described examples, but the most significant is that Green's function for a three-dimensional problem is much more complicated. It does not exist in tabular or closed analytic form, nor can it be adequately represented in the form of a power series; it must be calculated by numerical integration whenever needed during the program. Figure 6 shows numerical results for the backscattering cross section of a 2:1 spheroid obtained by the program. Some measurements, also shown, are seen to deviate a maximum of 1.5 dB from the calculated results, which is about the estimated accuracy of the experimental measurements. The calculations have also been checked against other calculations using a different approach, and have been found to agree with these within 0.1 dB.

It is possible to obtain another check on the accuracy of calculations of the type leading to the data shown in Fig. 6. This check originates from the reciprocity theorem for electromagnetic fields (see Fig. 7). We find the backscattering cross section by calculating the currents on the body and then integrating these currents to find the field reradiated in the direction of the transmitter. Once we know the currents, we can find the fields reradiated in any direction and consequently can find any desired bistatic cross section for the body as easily as we find the backscattering cross section. For example, we can calculate the energy reradiated at 120 degrees for a wave incident at 70 degrees (or any other pair of angles); we can also calculate the reradiated energy at 70 degrees for a wave incident at 120 degrees. Now, the reciprocity theorem requires that the reradiation in these two (or any two) reciprocal directions be the same. The computer, however, treats these situations as entirely separate cases; the current in the two situations, in fact, is quite different, and the reradiation pattern in general will be quite different. The required reciprocity relationship, to the extent that the computer has made errors in calculating either the two current distribu-

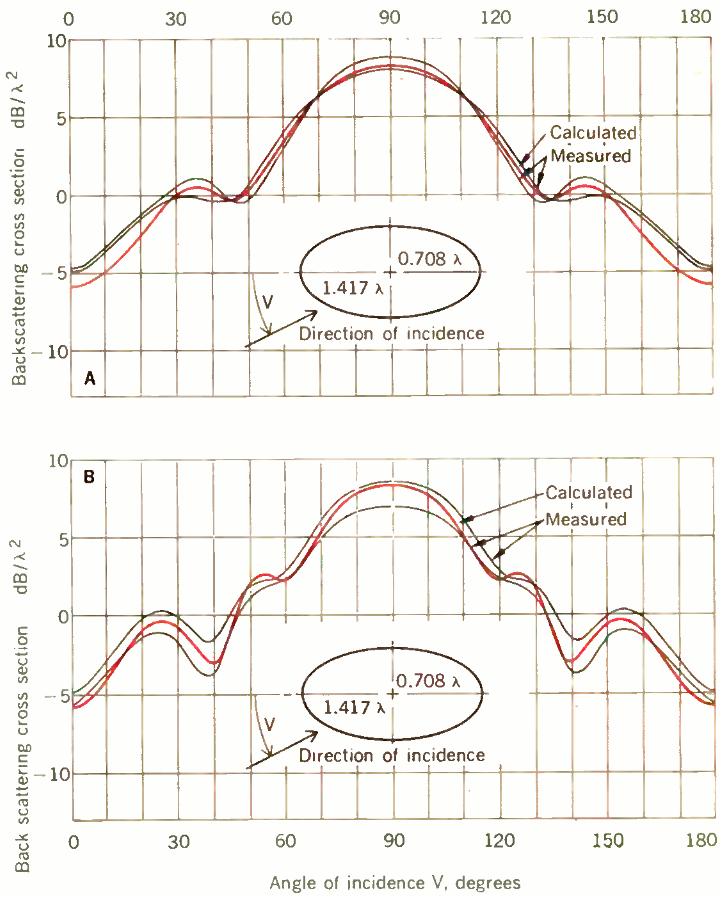
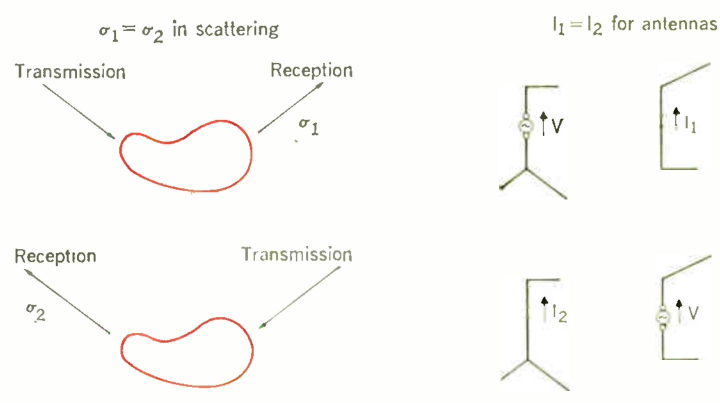


FIGURE 6. Scattering from a spheroid. A—Parallel polarization. B—Perpendicular polarization.

FIGURE 7. Simplified representation of the reciprocity theorem for electromagnetic fields.



tions or the reradiated fields from these distributions, will not be satisfied.

Program for wire structures

Another extremely interesting and useful type of problem that has been solved by the numerical integral equation method pertains to the radiation and scattering from structures composed of linear conducting elements—that is, from wires, conducting cylinders, tapered cylinders, or cones. This problem is reminiscent of the umbrella antenna, but for the more general problem, we must deal with the situation in which the dimensions are not small with respect to a wavelength. In this case, we consider the electromagnetic field, including all the near-zone components, radiated by the currents flowing on the elementary sections into which the antenna is divided rather than a simple scalar potential emanating from a static charge. Instead of requiring the potential to have a constant value on the surfaces of the antenna conductors, we require the tangential electric fields on the surfaces to be zero everywhere except in the terminal gap where the source is located. The reciprocity theorem also provides a check on the accuracy of calculations of wire antennas. Figure 7 shows a wire antenna with two gaps: one excited by an EMF and the other short-circuited. According to the reciprocity theorem, the ratio between the applied EMF and the short-circuit current is independent of which of the two gaps is excited.

When we can treat structures composed of arbitrary numbers of linear conductors, arbitrarily oriented and having arbitrary lengths, we are in a position to analyze a large majority of the antennas of practical engineering importance and to obtain information that has been heretofore virtually unobtainable. Such antennas as loops, dipoles, arrays of linear elements, Yagi antennas, rhombics,

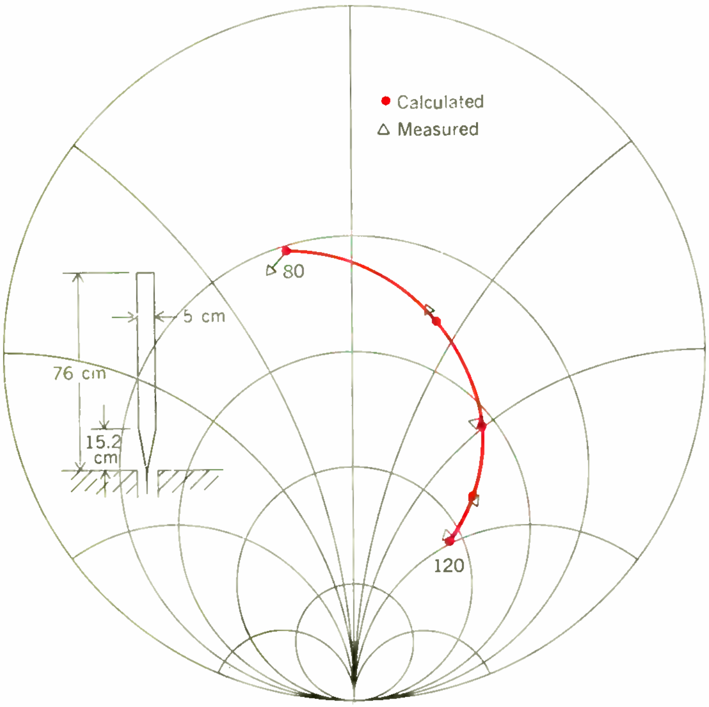


FIGURE 8. Calculated and measured input impedance of a flat dipole above ground from 80 MHz to 120 MHz in steps of 10 MHz. (Chart impedance = 50 ohms.)

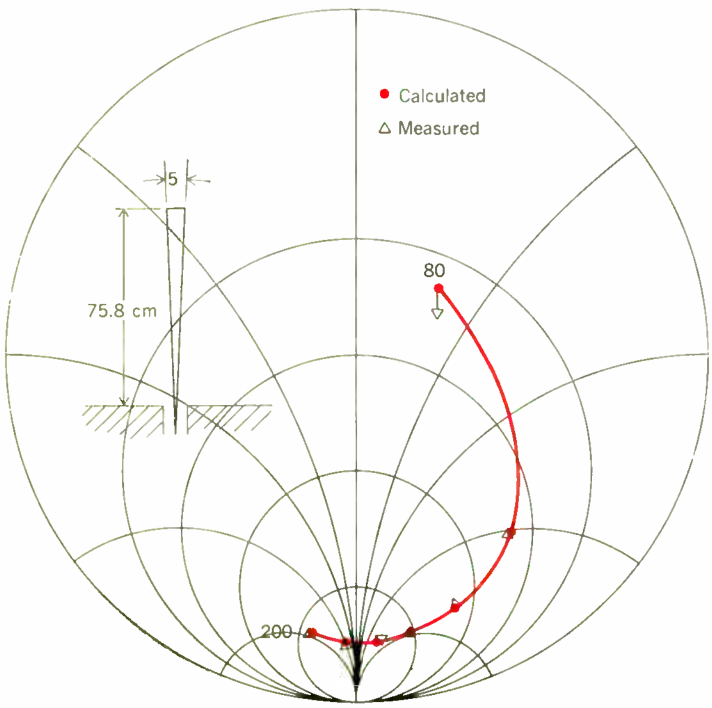


FIGURE 9. Calculated and measured input impedance of a conical dipole above ground from 80 MHz to 200 MHz in steps of 20 MHz. (Chart impedance = 50 ohms.)

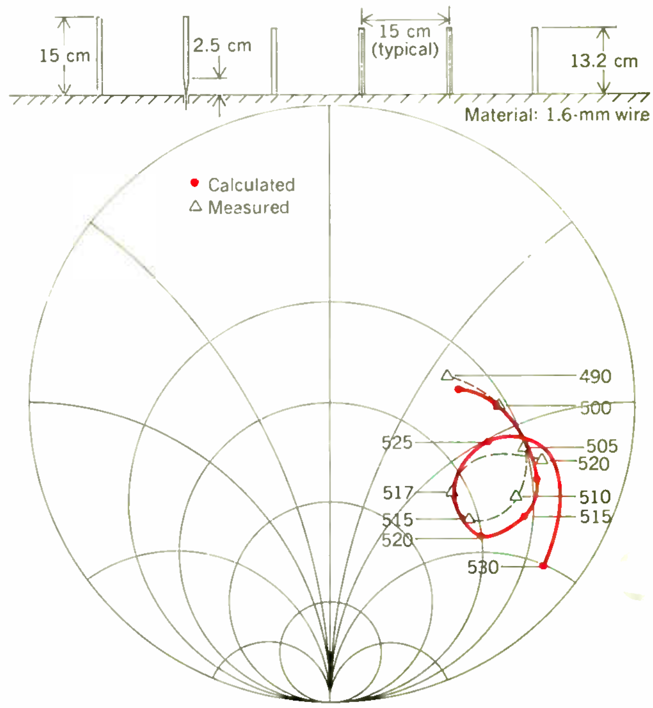


FIGURE 10. Input impedance of six-element Yagi antenna.

log-periodics—in fact, any antenna composed of slender conducting elements—can be calculated with any accuracy desired and characteristics of interest also established. When one develops a computer program to calculate the properties of almost any wire antenna with very high accuracy, it is essential to be able to check out the validity of the program by comparison with results obtained by other methods. The only theoretical case for which a comparison is worthwhile is the simple dipole antenna. In most cases one must, therefore, rely on experimental measurements for a comparison. The quantity best suited for a comparison is the input impedance of the antenna, which describes an important property of the antenna in terms of only two numbers: a resistance and a reactance. From an experimental viewpoint, the input impedance can be determined with much greater accuracy than either the current distribution or the radiation pattern of the antenna. From a theoretical viewpoint, the input impedance most often depends much more strongly upon approximations than either the current distribution or the radiation pattern. Therefore, the current distribution and the radiation pattern will usually be calculated with much greater accuracy than the input impedance.

Figures 8 through 11 show calculated and measured results for the input impedance of a number of wire antennas. Figures 8 and 9 show the input impedance of a vertical dipole and of a conical monopole. The agreement between calculated and measured results is very close.

Figure 10 indicates the input impedance of a six-element Yagi antenna array. The agreement between the calculated and measured results here is also quite good, though not as good as for the dipoles in Figs. 8 and 9. The difference is probably due mostly to experimental errors.

Figure 11 shows a 2.5-to-1 log-periodic array of five elements fed from a 200-ohm transmission line. The calculated and measured input impedance of this antenna over the 2.5-to-1 frequency band in which it should be operative is shown in Fig. 12. The agreement between the theoretical and measured results is seen to be extremely good; even the smaller loops of the impedance curve agree very well. With the wire antenna program we can treat, with surprisingly good results, some configurations that one does not at first associate with linear antennas.

Figure 13(A) provides an example of a structure composed of cylinders, tapered cylinders, and cones, that has more than a passing resemblance to an aircraft with a tail-

FIGURE 11. Representation of a log-periodic array of five elements fed from a 200-ohm transmission line.

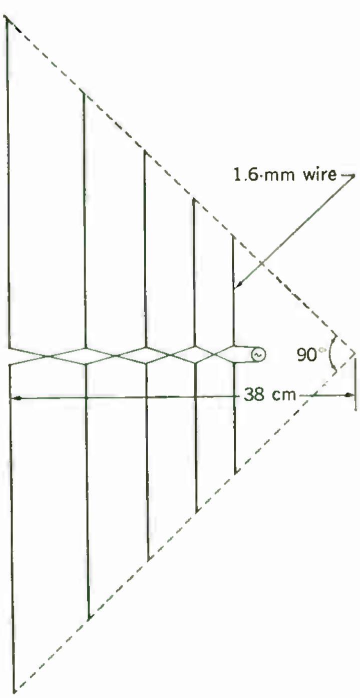
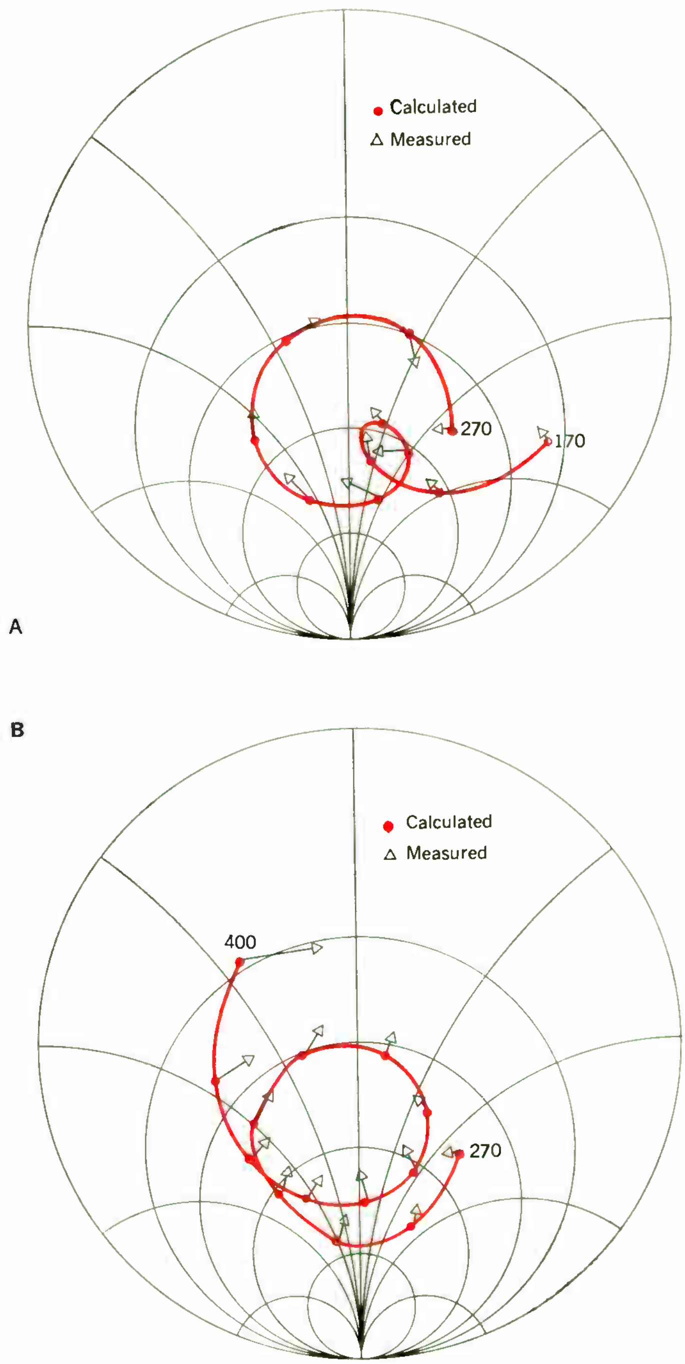


FIGURE 12. Calculated and measured input impedance of the log-periodic array of five elements. A—From 170 to 270 MHz in steps of 10 MHz. B—From 270 to 400 MHz in steps of 10 MHz. (Chart impedance = 50 ohms.)



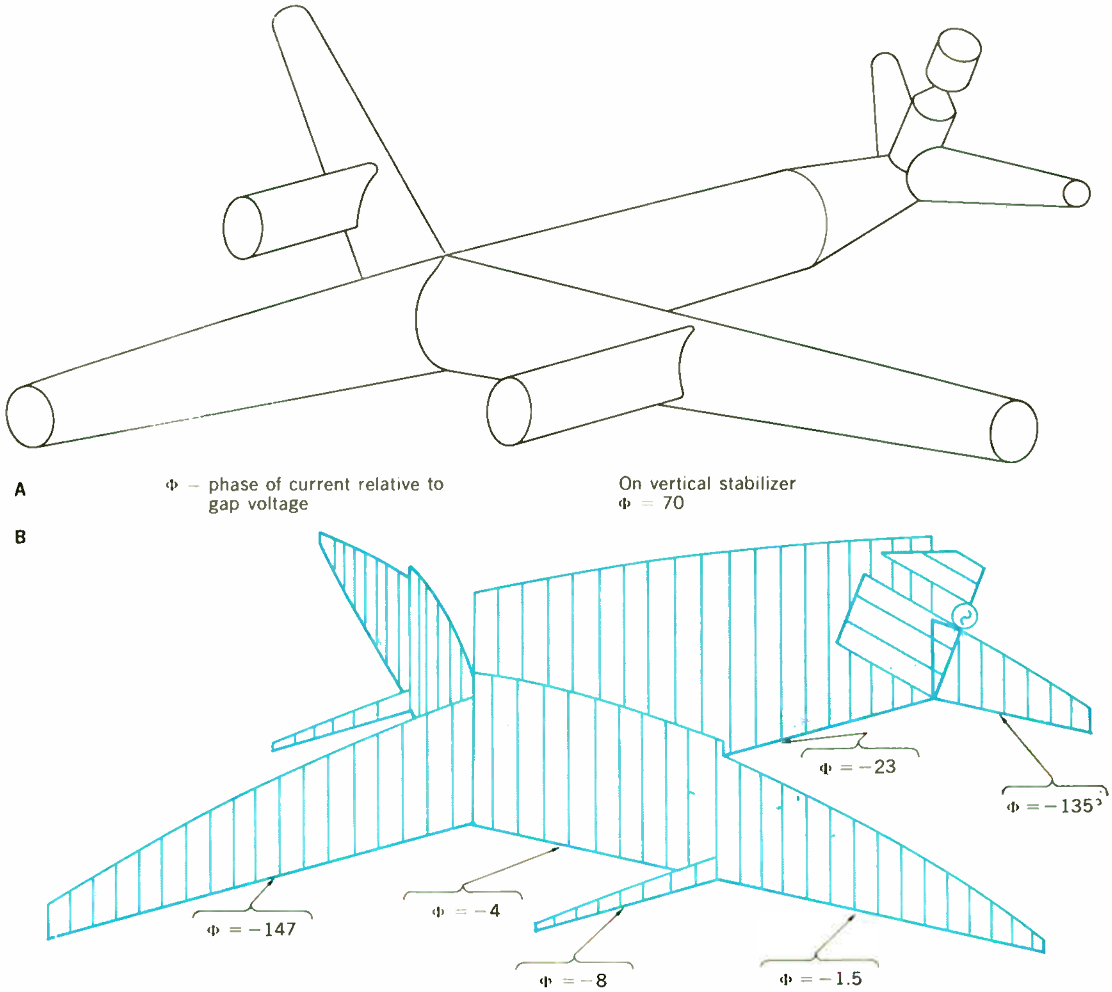


FIGURE 13. An RB-66 aircraft with tail-cap antenna. A—Crude model. B—Current distribution at airframe resonance frequency.

cap antenna. In this example all members, including the air-foil surfaces, have circular cross sections, and all except the vertical stabilizer with the tail cap are coplanar. The dimensions of the members are chosen so that the structure is an approximate electrical representation of the RB-66 aircraft. A much better representation could be obtained by using two or more parallel cylinders to represent the flattened air-foil surfaces, by dropping the nacelles below the wings and supporting them on struts as they are in the actual aircraft, and by employing other refinements. These refinements would increase both the time required to prepare the data for the computer and the computer time to obtain the desired solutions. If one were in earnest about the problem, however, such time would be well spent. Again, as much accuracy as desired could be obtained at the cost of increased computer time necessary as the result of the increased complexity of the structure analyzed.

In spite of the comparative crudity of the representation shown in Fig. 13(A), surprisingly useful and accurate results are obtained. (The inaccuracy, it should be pointed out, is not in the answers provided by the computer for the structure analyzed, but in the representation of the actual aircraft by that structure.) The computer calculation predicts the resonant peak in radiation resistance associated with airframe resonance as well as other aspects of impedance behavior. When suitable corrections are made to allow for the rather substantial disparity between the actual feed-gap region and that incorporated in the representation, the calculated impedances, both resistance and reactance, agree with the impedances measured experimentally on a model of the actual aircraft within approximately 20 percent at those points checked.

The computer calculation provides rather interesting data on the distribution of currents on the airframe members. These currents for a frequency near airframe resonance are shown in Fig. 13(B). In the figure, the airframe members are represented by lines forming the axes of the members and the currents are plotted vertically, picket-fence fashion, along these lines. The phases of the currents vary only a few degrees from one end of any member to the other and are indicated by the phases shown on the diagram, which apply to the currents at the center of each linear member composing the airframe. The finite values at the extremities show the amount of current flowing onto the flat end caps of the cylindrical members.

Another good measure of the accuracy of the results provided by the calculation is in the correspondence of the measured with the calculated radiation patterns. This comparison is illustrated in Fig. 14 for a frequency some-

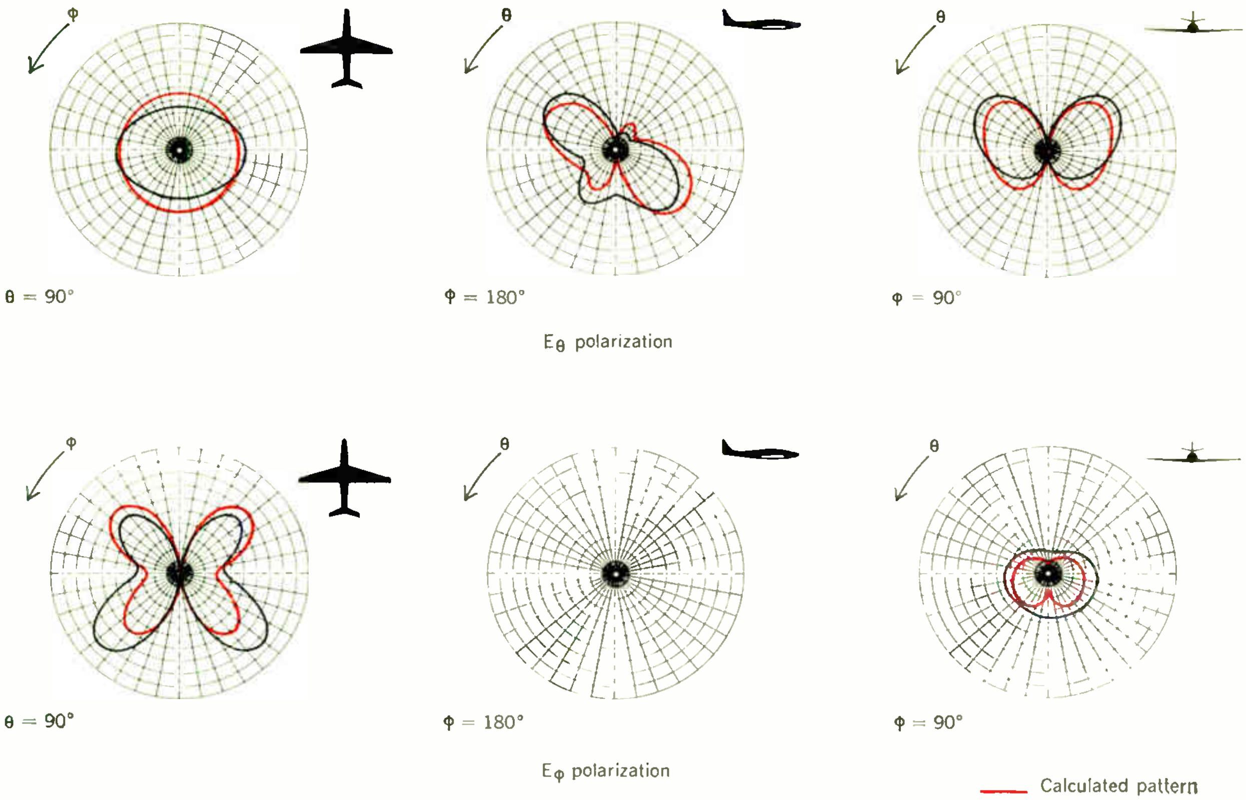


FIGURE 14. Comparison of calculated and measured patterns of the RB-66 aircraft with tail-cap antenna.

what higher than the airframe resonance frequency. (The experimental measurements were made a number of years ago, and only limited data were available.) It is evident that the computer has predicted all major features of the patterns. The only significant discrepancy is in the null below the aircraft in the longitudinal principal plane pattern (top center), where the computer predicts a significantly deeper null than was measured. The two small vestigial pattern lobes, the one directed up and forward and the other rear and down on this pattern, are predicted. Because the patterns are changing quite rapidly with frequency, the discrepancy in the downward null may well be due to a relatively minor misjudgment in the choice of dimensions for the linear element representation of the aircraft. It is almost certain that a more elaborate representation would overcome whatever discrepancies do exist.

Conclusion

The examples given show that high-speed computers enable the treatment by very general theoretical methods of practical engineering problems of virtually unbounded complexity. Besides the advantages of speed, economy, and flexibility relative to experimental methods, the numerical approach provides answers with a precision and wealth of detail completely beyond the reach of experimental techniques in most instances. This detail and precision can provide the basis for enhanced insight into the operation of the devices and structures analyzed, leading in most instances to designs that exhibit improved performance and are more efficient and economical. As the power of computers increases and the ingenuity with which they are applied grows, the realm of unsolved or unsolvable engineering problems will continue to diminish.

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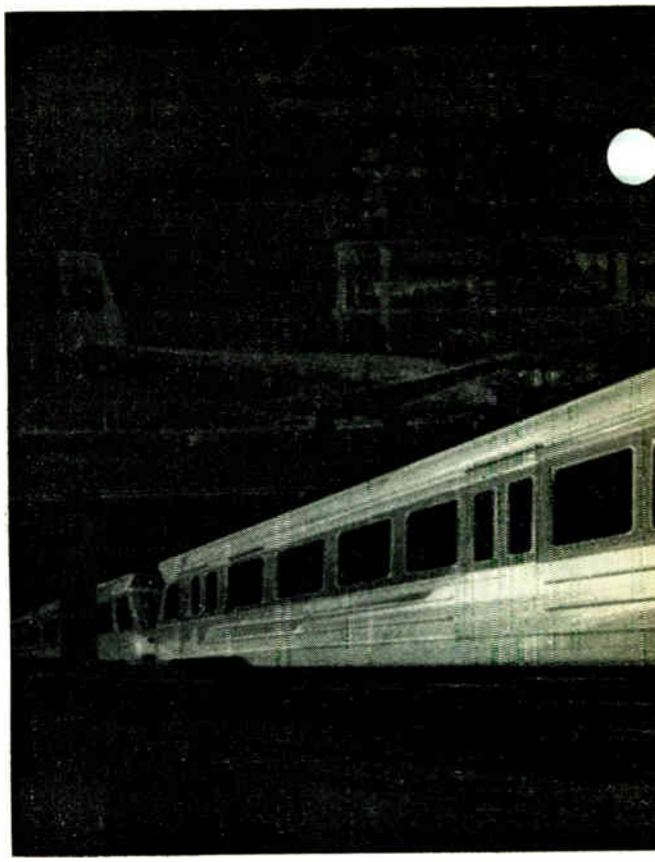
Railway vs. highway—the zoom of things to come



Although the advocates of expanded highway transportation will register their objections; exotic transit systems that will match subsonic aircraft speeds for short- and intermediate-distance interurban travel are no longer "whooshful" thinking; they are being planned and built in places where tires fear to tread

Gordon D. Friedlander
Staff Writer

The snob appeal of the private car—an overweight, superpowered, oversized monster—has trapped the American commuter to the point at which he is willing to endure incredible traffic jams, sickening exhaust fumes, and outrageous parking charges for the privilege of traveling to and from work in exclusive style, but questionable comfort. Perhaps the term "mass rapid transit," in itself, has had the unfortunate connotation of strengthening the commuter's belief that travel by such a plebeian-sounding system would somehow tend to degrade his standard of living. Nevertheless, the acceptance of mass rapid transit may be the only short-term solution to the concrete invasion of superexpressways into the heart of our major cities. Meanwhile, there has been no scarcity of ideas and proposals for both conventional and "far out" mass transit solutions. In fact, the entire subject has already been researched to exhaustion by technical committees, transportation experts—and collegiate science majors. Now it is time to implement the practical ideas by tangible action.

The big battle shaping up for the remainder of this decade will be between the advocates of mass rapid transit and the highway and automotive interests. This promises to be a protracted campaign of attrition, in which no quarter will be given (except in turnpike tolls), and no compromise for "balanced" transit systems will be readily accepted. In a balanced system, scientifically coordinated rail and highway traffic would supplement each other, particularly in urban areas.

Urban sprawl and urban crawl

During the past decade, the federal government has appropriated 100 times more money for highways than for mass transit, despite the fact that one conventional high-speed rail line could carry as many passengers in a given peak travel hour as 20 lanes of superhighway. Cities such as Houston and Los Angeles that have exhibited phenomenal growth patterns since the end of World War II have virtually no mass transit systems, and it is almost impossible to achieve any degree of mobility without a car. More than 50 percent of the sprawling area of Los Angeles is covered by asphalt and concrete. And, like many other American metropolises, it is a "car happy" city. A recent survey indicated that the 17 percent of its families who do not own cars are practically immobilized.

Nevertheless, the motor vehicle's demand on cities has reached a critical level. A portent of imminent car-sponsored catastrophes occurred in Boston on December

30, 1963, when all downtown traffic ground to a jarring halt at 3 P.M. This granddaddy of all snarls required six hours to untangle.

The car manufacturers, auto clubs, the construction industry, and public works officials, however, still insist that more and more highway construction is the only answer to the problem.

Rapid transit, U.S.A.

Mass transit, in a balanced transportation concept, includes interurban (up to 700 km), commuter (80 km), and intraurban systems. The term balanced transportation actually means a well-coordinated network of high-speed rail transit, automobiles on expressways, feeder buses, and outlying parking facilities—each used to its optimum advantage to complement and supplement the other interlocking systems.

There are presently 38 metropolitan areas in the United States (Fig. 1) of sufficient size to warrant balanced transportation systems.

The criteria for balanced transportation. Transportation planners have established three cardinal principles that must be met to attain the proper balance between adequate expressway facilities and railway rapid transit:

1. Metropolitan area residents must predetermine the type of city they want and can realistically attain in the future. All transportation planning is then predicated upon the fulfillment of these goals.

(Above) Typical rapid transit car of the Cleveland Transit System, which will provide high-speed service from downtown Cleveland to Hopkins International Airport.

2. All means of transportation must be interfaced, interrelated, and planned on an area- or region-wide basis as part of the basic scheme.

3. It should be recognized that rail rapid transit represents the optimum combination of speed, comfort, safety, convenience, and economy for the conveyance of large numbers of passengers in metropolitan areas.

The implementation of these criteria, however, is a large order that requires heavy investments in time, money, and imaginative planning. To build an ultra-modern coordinated network into the physical configuration of old established cities will inevitably entail considerable inconvenience, dislocation, and readjustment. But the ultimate prize should be worth the penalty.

Some existing systems—and their expansion

Chicago. Metropolitan Chicago was one of the first urban centers to realize the benefits of the balanced transportation concept. About 180 000 motor vehicles travel east and west over the 15½-mile (25-km) stretch of the Eisenhower Expressway (completed in 1956), from the Loop area of downtown Chicago to suburban Hillside, during any 24-hour weekday period. In peak travel hours, the Congress Street transit line of the Chicago Transit

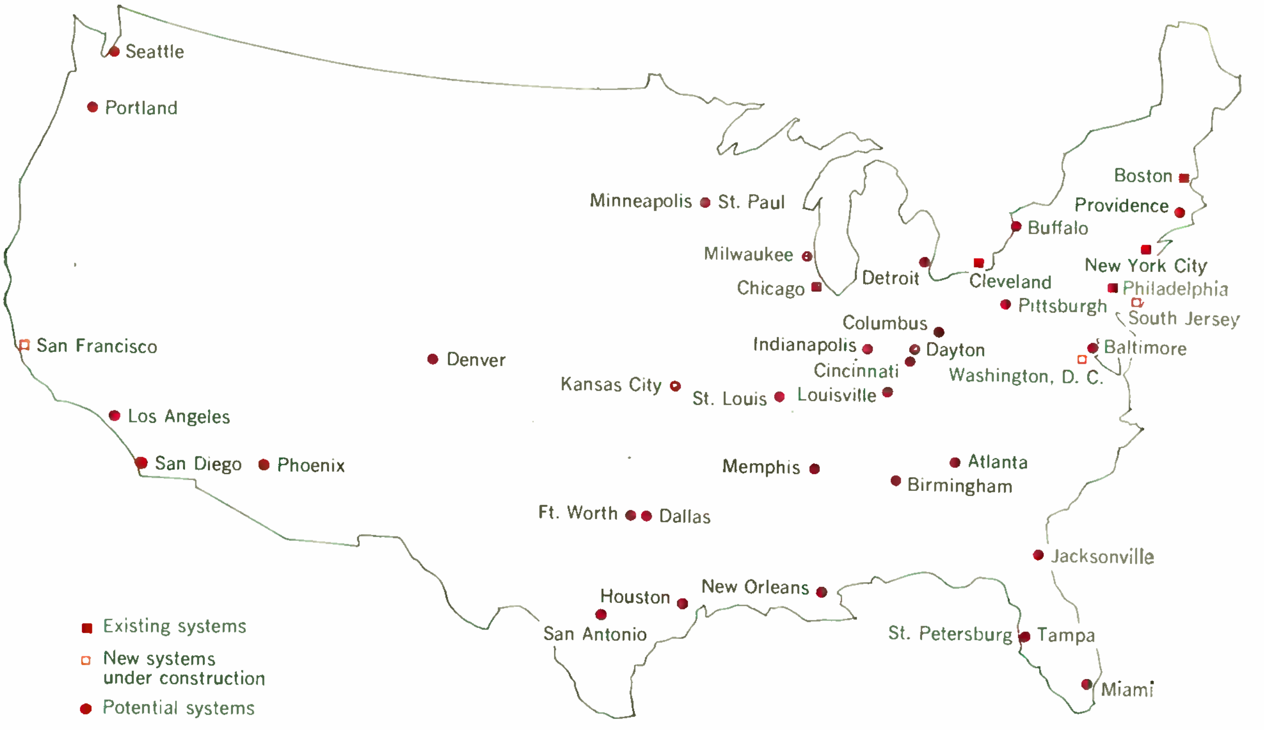


FIGURE 1. There are presently 38 metropolitan areas in the United States of sufficient size to warrant balanced transportation systems. As indicated on the map, some of these lines have been built or are under construction.

FIGURE 2. Map of the Northeast Corridor. The shaded area shows the densely populated "megalopolis" that stretches from Washington to Boston. This will eventually be served by a high-speed interurban rail route.

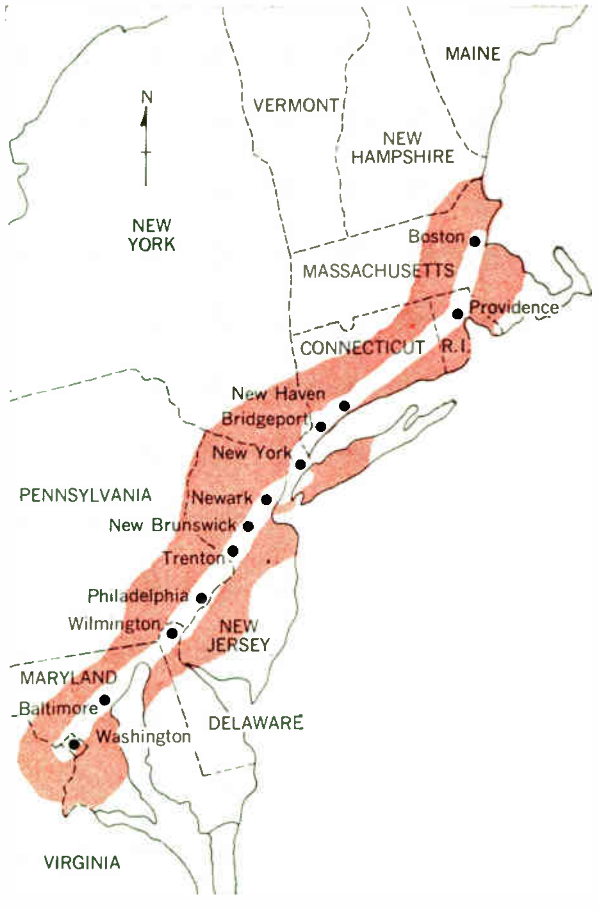
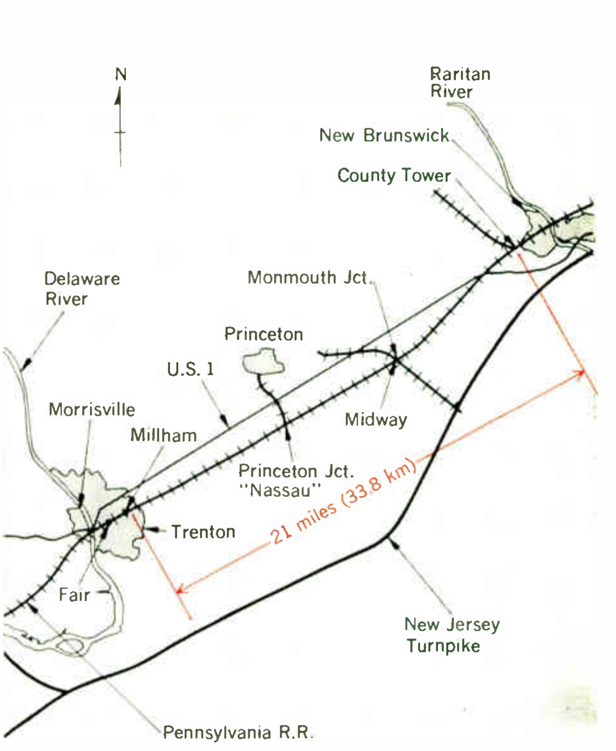


FIGURE 3. Map of the high-speed test track on the Pennsylvania Railroad, between New Brunswick and Trenton, used in the trials of equipment that will cut the traveling time on the New York–Philadelphia–Washington run.



Authority, whose right of way is in the center mall, carries about 50 percent more people on the 5.4-mile (8.7-km) run than the four-lane expressway that runs alongside. Although the expressway is saturated during rush-hour periods, the rapid transit line, which presently runs from the Loop to the city line, has an expandable capacity for future growth.

The rapid transit component of the Eisenhower Expressway has augmented the passenger-carrying capacity of the east–west corridor by some 500 percent, while simultaneously increasing the overall construction costs by only 10 percent to achieve a notable example of optimum mixed-transportation land use. The success of this venture has encouraged Chicago to appropriate the funds necessary to extend its balanced transportation network to include rapid transit facilities for the center malls of two more expressways.

Toronto. In 1954, the city of Toronto, Ont., completed the first phase of its proposed comprehensive rapid transit system. This was the $67 million, 4½-mile-long (7.2-km) Yonge Street line (along the principal business thoroughfare of the city) from Union Station north to Eglinton Avenue. Almost 70 percent of all the major residential and commercial construction from 1954 to 1959 was within walking distance of this subway.

In 1965, the north–south University Avenue loop line, running parallel to the Yonge Street subway, was put into service; and, last year, the 8-mile-long (12.8-km) Bloor–Danforth line (the major east–west link) completed the third phase of the ambitious transit project. In addition to providing millions of dollars in increased tax revenues for Toronto, the city has been able to phase out a number of its surface bus and tram lines to ease the traffic congestion along many downtown streets. City officials estimate that the Bloor–Danforth line alone will initiate a $2 billion building construction boom along its route.

Cleveland. The Cleveland Transit System (CTS), one of the newer American transit operations, began the construction, in June 1966, of a 4-mile-long (6.4-km) extension to Hopkins International Airport. When this spur is completed in mid-1968, Cleveland will become the first city in the United States to have a rapid transit system (see title illustration, p. 62) serving a major airport. Only the airports at Brussels and Tokyo have a similar service.

Cleveland is a good example of a balanced transportation concept, since the CTS maintains extensive suburban parking facilities for the accommodation of more than 5000 cars, and offers comprehensive feeder bus services to intertie sections of the city that are not presently served by rail rapid transit.

About half of the $14 million cost of the extension to the airport is being financed by the U.S. Department of Housing and Urban Development.

San Francisco. Despite considerable local public apathy and bureaucratic administrative complexities, San Francisco's Bay Area Rapid Transit (BART) system dramatically stands as the foremost symbol of a comprehensive high-speed, computer-controlled interurban rail line that is based upon advanced concepts and engineering principles. Nevertheless, BART has been plagued by disputes ranging from esthetic design to cost estimates that have soared as high as $1.2 billion (of which sum the federal government has only contributed $26 million thus far). But although the city is further harassed by litigations and the resignations of consultants and transit officials, BART *is still being built.*

. . . And the others. At present, some 23 cities in the United States, including Philadelphia, Boston, New York, Atlanta, Washington, Baltimore, and Seattle, have far-reaching plans for and intraurban rail transit systems.

The Northeast Corridor

Perhaps the area that has received the most attention from transportation experts in recent years is the heavily traveled Northeast Corridor (Fig. 2), the 450-mile (713-km) stretch from Washington through New York to Boston, with feeder lines on portions of the Long Island Rail Road and in the metropolitan Boston complex.

Present federal program. The High-Speed Ground Transportation Act, passed by the U.S. Congress in 1965, provides a twofold program in which:

1. Demonstration projects of moderately high-speed trains—about 125 mi/h (56 m/s)—will soon be operated on the Pennsylvania Railroad between Washington and New York, and on the New Haven Railroad between New York and Boston.
2. A longer range R & D program will be set up from which a new and much higher speed ground transport system could be designed.

Of the $90 million authorized by the government under the act, about $11 million will be spent on the improvement and speeding of passenger service on the New York–Philadelphia–Washington run. But some $44 million in costs will be borne directly by the Pennsylvania Railroad. If the project eventually becomes profitable, the federal government will recoup its investment.

The primary purpose of the demonstration projects just mentioned is passenger response to the improved interurban services. The results of the reduced running times and upgrading of other passenger facilities will be measured by a detailed data-collection program. The second portion of the program, the long-range R & D effort, is presently under way at M.I.T., and at Rensselaer Polytechnic Institute, where the feasibility of a revolutionary tube transit concept (to be discussed later in this article) is being investigated.

New York–Washington—faster runs are coming

The U.S. Department of Transportation (DOT) is presently conducting a series of test runs on a 21.2-mile (34.2-km) section of the Pennsylvania Railroad's tracks between Trenton and New Brunswick, N.J., as part of its High-Speed Train Evaluation Project (HIGH-STEP). This section of track was selected (Fig. 3) because it is free of grade crossings and contains only four moderate curves in its run. Welded rail was installed, thousands of ties were replaced, interlockings were renewed, and the track profile was raised or lowered to a uniform vertical control elevation. A heavier trolley contact wire also was installed in the catenary to reduce loss of contact at high speeds.

The four self-propelled test cars (designated T-1 through T-4) were specially built for DOT as "rolling laboratories" (Fig. 4) that are equipped with test instrumentation provided and operated by Melpar, Inc., a subsidiary of Westinghouse Air Brake Company.

The testing equipment. In the test configuration, there are four instrumentation subsystems:

1. Pantograph and catenary dynamics, car T-1.
2. Track and wheel dynamics, car T-2.

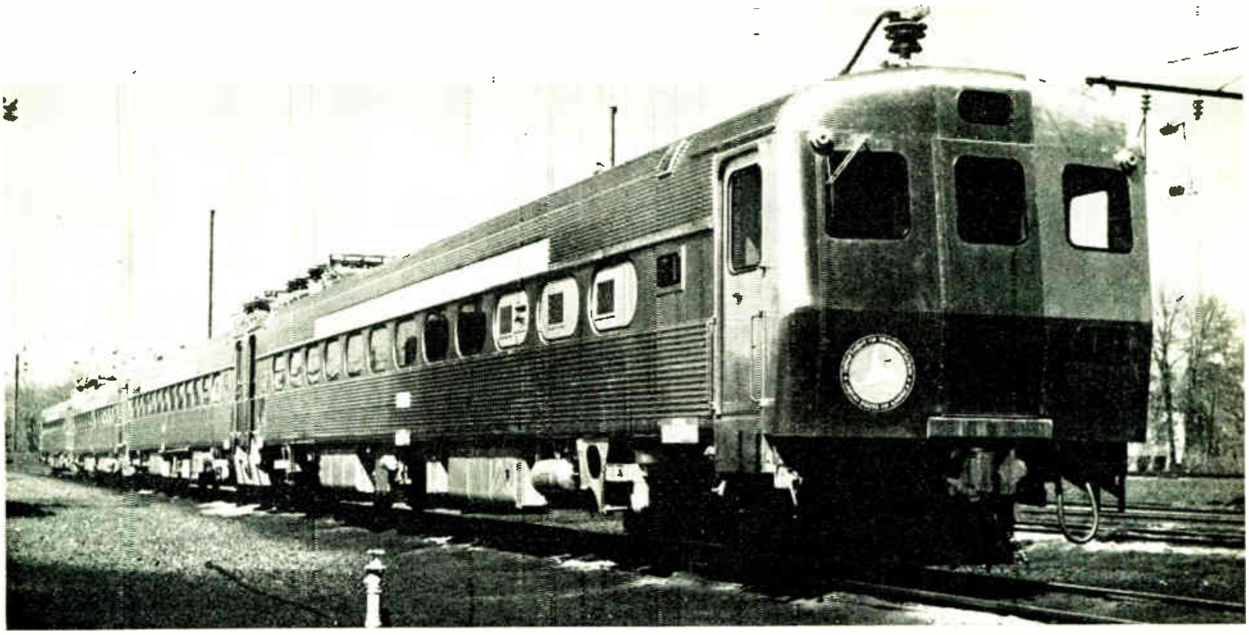


FIGURE 4. Four of the self-propelled test cars, capable of speeds in excess of 150 mi/h (67 m/s), presently in use by the U.S. Department of Transportation for its HIGH-STEP trials.

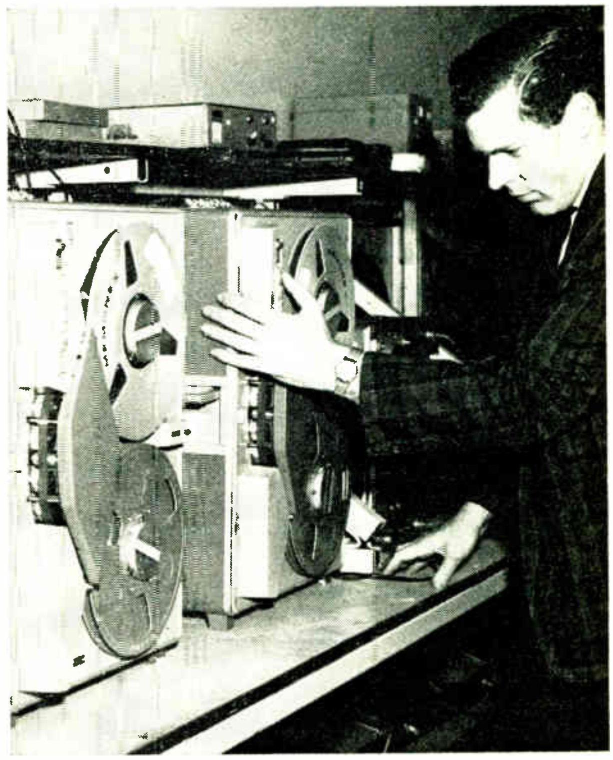


FIGURE 5. Field engineer on research rail car loads magnetic tape into an Ampex FR-1300, 17-track tape recorder, which stores information for subsequent computer processing. Information is recorded simultaneously for all analog measurements taken by 300 sensors on four test cars.

3. Truck and car dynamics, car T-4.
4. Track and catenary dynamics, at the wayside.

Distances, displacements, speeds, accelerations, loads, strains, pressures, temperatures, and electric voltages, currents, and power are monitored continuously by devices selected to meet the special conditions of each measurement. All physical phenomena are converted by transducers to an electric signal having a known analog relation to the measurement.

Some of the electric signals are immediately recorded on chart paper for use at the time of measurement. All signals are also recorded in analog form on magnetic tape to permit computer processing of the information. Recording facilities are kept to the minimum compatible with the research requirements by multiplexing the signals from the sensors before they are recorded on the data tapes. This process permits the recording of 150 data channels on only five magnetic tape tracks.

Transducer-produced information is supplemented, in three instances, by recorded images from closed-circuit television systems. And measurements not conveniently obtained by conventional instrumentation can be made by using the stop-motion capability of the television recorder.

A variety of devices are used to scan and inspect all of the signals that are being recorded. For example, television monitors give a continuous display of the pictures going onto the video recorder; oscilloscopes and various meters permit the inspection of the measurement signals being recorded on magnetic tape. In addition, a four-channel chart recorder is used to provide continuous analog records of special-interest information.

All instrumentation and recording equipment has been designed for maximum compactness and portability. For operational convenience, all data generated by the car-borne systems are recorded in car T-2 (Fig. 5). The wayside recording equipment, mounted in a panel truck, is coordinated automatically with the passage of the test cars. Thus the maximum capability is provided for under-

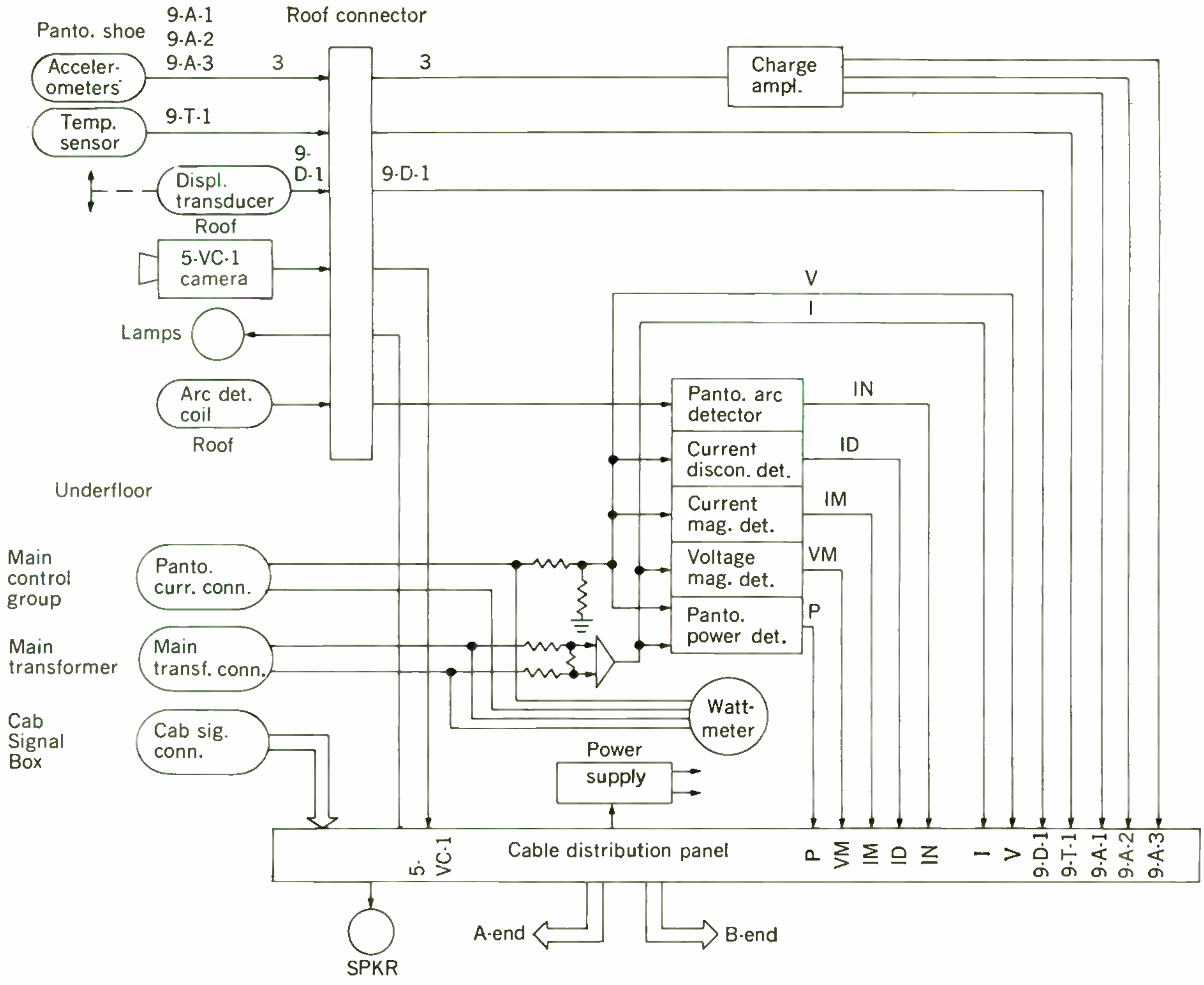


FIGURE 6. Block diagram showing the dynamic instrumentation used in recording the mechanical and electrical performance characteristics of the power-collection system on a high-speed test car.

standing the interactions of a high-speed railroad car with the track, other cars and trains, and the overhead power supply system.

In detail, for example, the purpose of the car T-1 instrumentation is to measure the mechanical and electrical performance of the pantograph power collection system from the overhead catenary. Longitudinal, vertical, and lateral accelerations of the pantograph shoe are measured by servo accelerometers mounted in a Teflon container under the shoe (see Fig. 6 circuit diagram). The vertical motion of the pantograph is measured by a rotary linear variable potentiometer that is mounted on the roof of the car and connected to the pantograph arm by a nylon line.

The existence and duration of arcing between the pantograph shoe and the catenary contact wire is detected by a tuned coil wrapped around the high-voltage lead from the pantograph. A closed-circuit television camera, mounted on the roof of the car, permits the motions of the various pantograph parts and the trolley wire to be observed and recorded.

Eyewitness reports. Last May 24, correspondents were invited to witness one of a series of high-speed tests, conducted between New Brunswick and Trenton, with the four-car multiple units.

Although the on-board and wayside visitors were impressed by the smooth-riding qualities and the blur of motion as the train whooshed by at 156 mi/h (70 m/s), some observers reported that there was considerable and rather violent lateral oscillation in the catenary in the wake of the four-car unit. And *The New York Times'* correspondent mentioned that the vacuum produced by the train has a rather nasty habit of sucking out the windows of some of the older conventional passenger cars as they pass each other on adjacent tracks. These problems would seem to indicate that parallel track clearance specifications, curve radii, superelevations, and catenary design will have to be modified before future regularly scheduled runs at maximum speeds can become practical.

The new service—Phase I. Fifty new cars, each 85 feet long (25.9 meters) by 10½ feet wide (3.2 meters), are presently being built for the Pennsylvania Railroad by the Budd Company. These dimensions, in the interest of maximum passenger comfort and safety, are larger than conventional railroad standards. Each of these self-propelled units will contain four 300-horsepower (221-kW) General Electric series-wound dc traction motors. This power package will permit the units to accelerate to 125

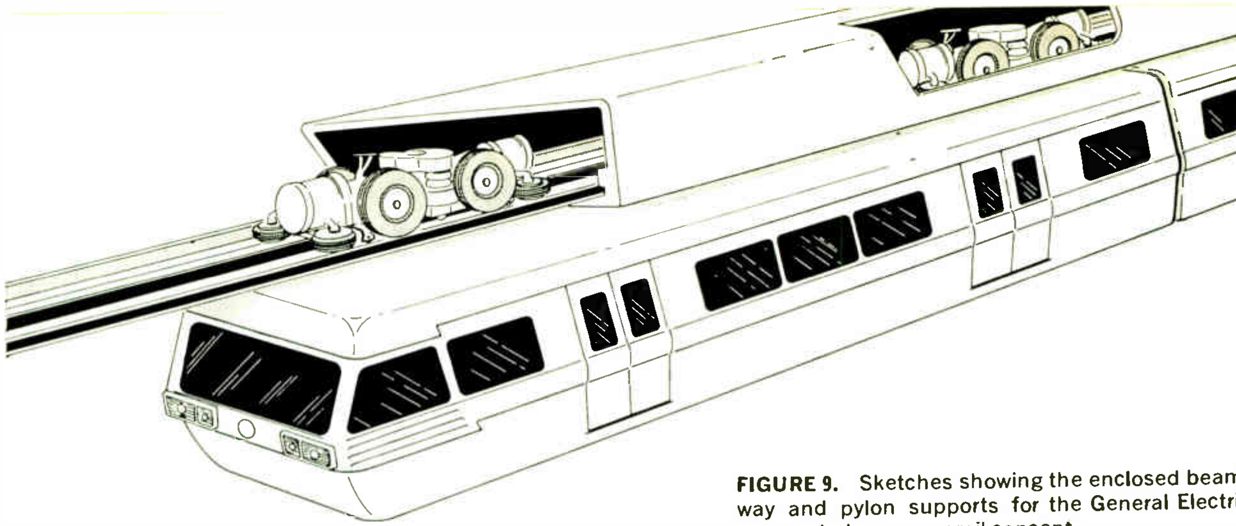
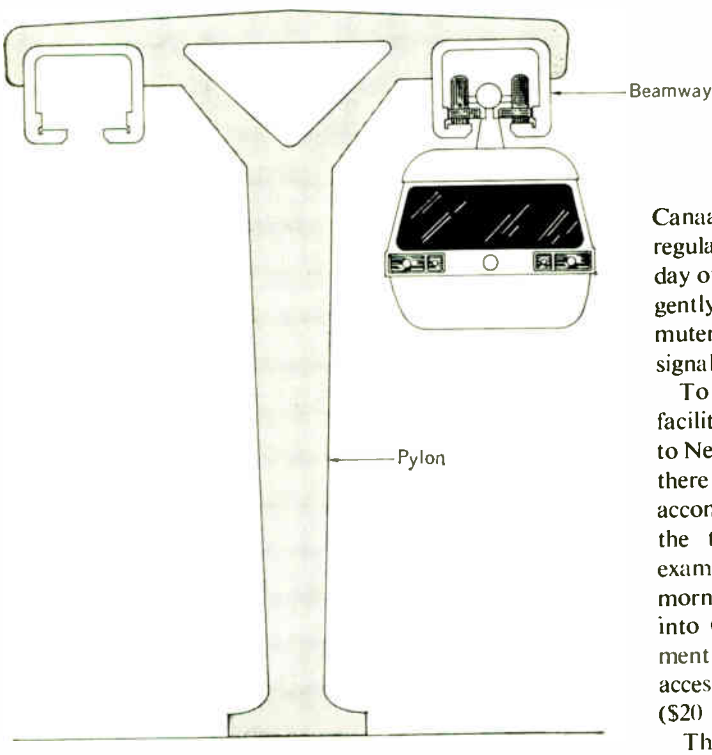


FIGURE 9. Sketches showing the enclosed beamway and pylon supports for the General Electric suspended-car monorail concept.



wide by 13-foot-high (25.9 by 3.2 by 4.0 meters) air-conditioned, 122-passenger-capacity, stainless-steel and aluminum cars (Fig. 8) will have a top speed of about 100 mi/h (44.5 m/s).

Improved access to Manhattan—Phase II. Today, the LIRR has only one terminal in Manhattan—Pennsylvania Station. More than half of the 80 000 daily passengers on this railroad must either backtrack to the East Side, or make their way uptown or downtown on the overcrowded facilities of the New York City subway system.

The MCTA's consulting engineers are working with the New York City Transit Authority in developing the detailed engineering plans necessary to give LIRR commuters direct, no-transfer service to lower Manhattan, and to share an expanded, four-track tunnel project under the East River at 63rd Street to bring passengers from Long Island to the midtown East Side office area.

Phase III—an interstate scheme. The New Haven Railroad's west-end passenger service (New Haven to New York on the main line, and Waterbury and New Canaan to New York on the branch lines) carries 70 000 regular commuters and casual passengers on each working day of the week. The railroad, which is in receivership, urgently needs massive capital investment for new commuter cars, extended electrification, and station and signal equipment improvements.

To replace this railroad with alternative highway facilities from Connecticut, through Westchester County to New York City, would cost more than $1 billion. Also, there would be the almost insurmountable problem of accommodating a further deluge of motor vehicles in the traffic-choked Manhattan business districts. For example, during a one-hour peak period each weekday morning, the New Haven line carries 15 500 passengers into Grand Central Terminal. To duplicate this movement by automobile would require 14 lanes of limited-access highway—at a cost of about $32 million per mile ($20 million per kilometer).

The MCTA and the Connecticut Transportation Authority have made the following five-point, joint recommendations to the governors of New York and Connecticut for the upgrading of interstate commuter service on the New Haven Railroad over the next five years:

1. The two transit authorities, acting as agents for New York and Connecticut, should lease for 99 years the rights of way, stations, shops, and electric power installations of the New Haven Railroad from Woodlawn station in the Bronx, to New Haven, Conn.—including the New Canaan, Danbury, and Waterbury lines.

2. The two authorities should enter into a 99-year contract with the New York Central Railroad for trackage rights from Woodlawn station to Grand Central Terminal, and for the joint use of Grand Central and the 125th Street station (Manhattan).

3. The interstate agencies would lease some of the New Haven's existing rolling stock until modern and efficient equipment could be built and put into service.

4. The agencies would undertake an $80 million modernization program to update the electrification, stations, signal equipment, and repair shops of the New Haven Railroad, and would provide an all-modern fleet

FIGURE 10. Budd–Sikorsky "skylounge" being airlifted in recent demonstration in Philadelphia. Prototype model carries a maximum of 23 passengers.

of self-propelled commuter cars for the interstate service.

5. The two authorities would enter into an agreement with the trustees of the New Haven Railroad for the operation and management of the New York–New Haven commuter service, and the distribution of passenger revenues accrued.

An aerial transport system

Every air traveler has come to recognize the often frustrating airport-to-center-city ground transportation problem. And every commuter has been annoyed by the unreliable service afforded by antiquated rolling stock traveling over railroad rights of way that were built more than 50 years ago. It is paradoxical that although we are in the aerospace and nuclear age, thousands of captive riders are still forced to rely upon ground transportation facilities that have not been significantly upgraded since the turn of the century.

Based on the design concept of the French beamway suspension SAFEGE transport system, the General Electric Company has developed a monorail configuration that will afford passenger safety and comfort in traveling to and from airports at speeds up to 100 mi/h (44.5 m/s) under all weather conditions. For example, traveling at high speed from Dulles International Airport to downtown Washington, a distance of 25 miles (40 km), would require less than 20 minutes. This aerial system, of course, could be readily adapted for commuter service to metropolitan suburbs.

The aerial structure can be erected economically over expressway median strips or adjacent to heavily trafficked arterial highways.

Enclosed track is a notable feature. The enclosed beamway (Fig. 9) contains the running surface for the power units, vertical rails for the guide wheels, and electric power transmission lines for vehicular propulsion, signaling, and communication. The underside of the beam is designed to permit the passage of the suspension equipment that connects the power unit to the roof of the vehicle. A permanently dry track would ensure uniform high performance efficiency, even in bad weather.

Advantages and disadvantages. According to its developers, the system has the advantages of

1. Utilizing the "third dimension"—the valuable air space over congested areas.

2. High-strength supporting pylons that occupy minimal ground space necessary for construction.

3. Negotiating small-radius curves and thus parallel the horizontal and vertical curvatures of conventional highways.

4. Electrically powered bogies (trucks) running within the enclosed beamway on pneumatic tires to provide quiet and smooth transportation.

5. No smog-producing fossil-fuel exhaust fumes.

The monorail concept, in its many variations, is hardly novel. Although a four-mile-long (6.4 km) dual-beamway line was built for Seattle's "Century 21" exposition in 1961, a monorail demonstration system was a feature of the New York World's Fair 1964–1965, and a "minirail" line is presently in use at Montreal's "Expo 67," the general public reaction to the monorail scheme in the United States, unfortunately, has been far from wild enthusiasm. Critics cite the adverse esthetic and functional effects of building such lines over already congested city streets, and the relative inflexibility of the systems to eventual expansion to meet projected increases in population. Also, some city planners feel that new concepts in helicopter–bus service can better meet the needs of city-center-to-airport transportation.

The helicopter-borne 'skylounge'

The Budd Company, in a joint cooperative venture with the Sikorsky Aircraft Division of United Aircraft Corporation, on May 13, displayed and publicly tested its prototype combination "skylounge" and "skycrane" modules (Fig. 10) at the Northeast Philadelphia Airport.

The skylounge module is an aluminum pod, 30 feet long by 8 feet wide by 8 feet high (9.14 by 2.44 by 2.44 meters), that weighs about 12 000 pounds (5450 kg) empty. In use, the wheel-mounted pod—capable of carrying 23 passengers and their luggage—could be hauled as a trailer by the truck-tractor element of the system from downtown passenger collection points to a center-city heliport pad. Here, the turbine-powered skycrane module is coupled to the loaded pod, and the ensemble is airlifted to the main airport.

The Los Angeles Department of Airports is interested in developing, with Budd and Sikorsky, the first working version of these vehicles, capable of airlifting 44 persons, between downtown Los Angeles and International Airport. The first of such units could be in operation by 1970.

A new concept for present transit system design?

The writer has recently received an interesting commentary and copy of a patent application from Raymond A. Young, an electronics engineer associated with Hughes Aircraft. His proposal, which has received considerable publicity in West Coast newspapers, alleges at the outset that "the most significant thing about present system planning is the complete lack of any new ideas. For example, the BART system is simply 1890 warmed over, using 28-ton cars which are decelerated and accelerated to pick up and let off as few as one passenger—resulting in a low efficiency, low average speed and poor accessibility, coupled with installation costs that are impossible to cover with fare-box revenues. . ."

Monorail and capsules. Mr. Young's scheme utilizes lightweight overhead steel rail lines to suspend "minicapsule" cars that carry a maximum of four passengers each. The capsules require no motive or braking power of their own, since all power is supplied by a transporter unit capable of carrying 200, or more, of the individual cars, and all braking equipment is built into the support rails at the stations.

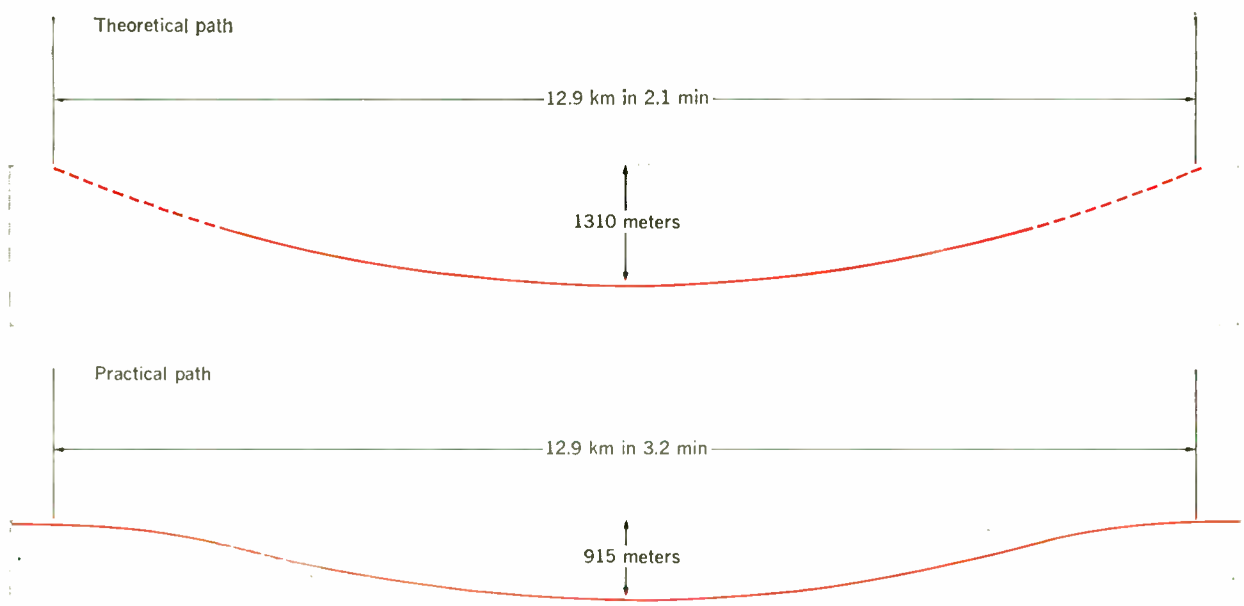
The transporter rail would essentially consist of an elongated, flexible metallic band, which would be propelled along the monorail by a synchronous electric motor connected to drive wheels at its forward end for engaging the monorail. With this system, each capsule may be picked up or dropped off, by means of its self-contained retractable wheels, as the transporter rail—traveling at a constant speed of 60 mi/h (26.8 m/s)—passes station facilities. When the wheels are fully supported on the transporter rail, the car experiences a programmed smooth acceleration to the speed of the traveling rail. A similarly programmed braking is accomplished when the car is disengaged.

In operation, a city could be crisscrossed by many such monorail lines. With a number of transporter units running on the system, interchange would be possible from one rail line to another, thereby creating a high-speed grid, or network, in which the capsules would have a degree of directional flexibility, within station limits, that would be comparable to a taxi. According to Young, the entire network could be completely automated and controlled by a central computer that would allow ride charges to be based upon length of trip and on a monthly billing basis.

Young believes, for example, that traveling via his capsules in Los Angeles would be much faster than using the existing freeways. He also feels that his system would provide speedier service than helicopters from downtown Los Angeles to International Airport.

Unfortunately, however, the esthetic problems created by this and other monorail system proposals for downtown areas will undoubtedly militate against such

FIGURE 11. Profile of the gravity-vacuum tunnel concept showing the theoretic and practical pendulum paths for this scheme over a 12.9-km station-to-station run.



schemes. Cities that have recently eliminated their unsightly elevated transit lines to upgrade the appearance and property values of principal thoroughfares will certainly not want to re-establish overhead monorail structures.

A 'far-out' concept: the gravity-vacuum tunnel

In theory, the gravity-vacuum tunnel (GVT) concept bypasses the conventional horizontal acceleration limitation (restricted by passenger comfort to about 1.4 times the pull of gravity) by employing a pendulum motion in which the horizontal acceleration component is not noticeable. Such a tunnel configuration (Fig. 11) drastically reduces vehicle propulsion power requirements—particularly critical at high speeds—by

1. The use of an evacuated tube (a partial vacuum equivalent to an altitude of 70 000 feet, or 21 350 meters), in which gravity is employed for much of the acceleration and braking power that is needed.
2. The sequential use of air pressure to push a train of vehicles during acceleration, and to apply a piston effect in braking the vehicles during deceleration.

Gravitation, plus pneumatic power. As indicated in Fig. 11, the practical tunnel profile arcs down and up again to let GVT trains take full advantage of gravity, both to accelerate and decelerate the train reliably, smoothly, and efficiently. Depth at the midpoint of the GVT arc depends upon the distance between stations. With stops a mile (1.6 km) apart, the average distance for an urban transit system, the tunnel invert depth would be about 300 feet (91.5 meters) below grade (Fig. 12). A vehicle freely rolling down this slope would attain a maximum speed of 85 mi/hr (38 m/s), which would diminish rapidly as the train swept up the arc to the next station. For stations 1½ miles (2.4 km) apart, the midpoint depth would be 500 feet (152.5 meters), for a maximum speed of 120 mi/h (53.7 m/s).

The other source of motive power for the GVT train is a continuous bank of electrically powered pneumatic compressors, cross ducts, and cross-connection valves, placed underground and adjacent to the parallel transit tubes. The pumps would reduce air pressure within the tubes to about 1.5 percent of normal atmospheric pressure. This serves to reduce air-drag losses as a train passes through the tube, and supplements the gravitational forces in starting and stopping the vehicles.

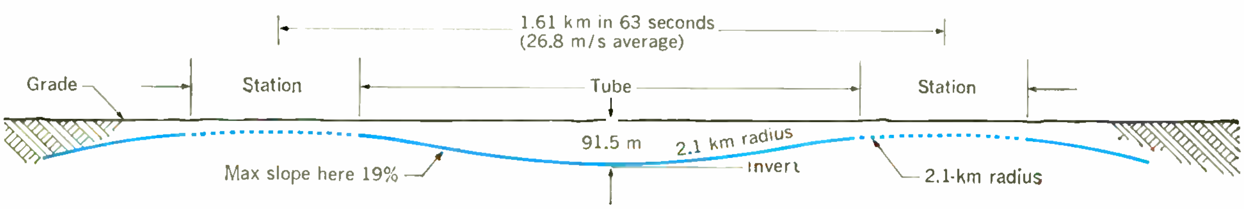
In operation, normal air pressure, acting against the rear end of the train, at the start, applies a thrust of about 70 tons to accelerate the train on the downward arc in the evacuated tube. As the train passes, air replaces the vacuum behind it to assist in the acceleration. When the train reaches the lowest point of the arc, the start valve and acceleration valves are closed. The train continues to accelerate, but at a decreased rate, as the cross-connection ducts close as the vehicle passes in order to contain the air in the rear. On the upward arc, the train begins to compress the residual air in the tube ahead of it, and this cushion serves as a gradual braking force. Finally, when the air compression ahead of the train reaches normal atmospheric pressure, the deceleration and terminal valves are opened. These are closed again as the train passes.

Tracks and trains. The proposed train is essentially a long, pressure-tight, articulated cylindricalc apsule, with a diameter two inches (5.1 cm) smaller than the 9½-foot-diameter (2.9 meters) steel tubes. Each car would be 65 feet long (19.8 meters), and designed to run on four-wheel mountings over twin steel guide rails that can be welded to the floor of the tube. Entrance and exit doors, on opposite sides of the cars, would be pressure-tight sliding panels that retract into the ceiling of the vehicle. Each car would accommodate 64 seated passengers.

Tunnel construction. The tunnel tubes, even at great depths below grade, could probably be constructed through deep bedrock by modern hydraulic boring machines. Figure 13 shows a typical twin-tube tunnel cross section.

To achieve ultimate smoothness in the high-speed ride, a "dynamic flotation" technique is proposed in the provision of a water cushion that will flex under load. Thus the tube in the no-load condition (shown at left in Fig. 13) will be submerged in water to a depth of about 20 inches (51 cm). Small structural disturbances will also be absorbed by the self-leveling of the water to ensure

FIGURE 12. Profile of the GVT system as applied to a typical metropolitan subway system, with stations spaced approximately 1.6 km apart.



Velocity at bottom, m/s

	Full	Empty
Due to gravity	38	38
Due to vacuum	35.8	42.5
Total	51.5	56

Sensible acceleration

	Full	Empty
Vertical	±0.13 g*	±0.15 g
Horizontal	1.1 m/s²	1.7 m/s²

*$g = 32.2\ ft/s^2 = 9.8\ m/s^2$

Basis

2.9-meter diam. train, 427 meters long (31 cars)
"Full": 1250 seated, 1250 standees

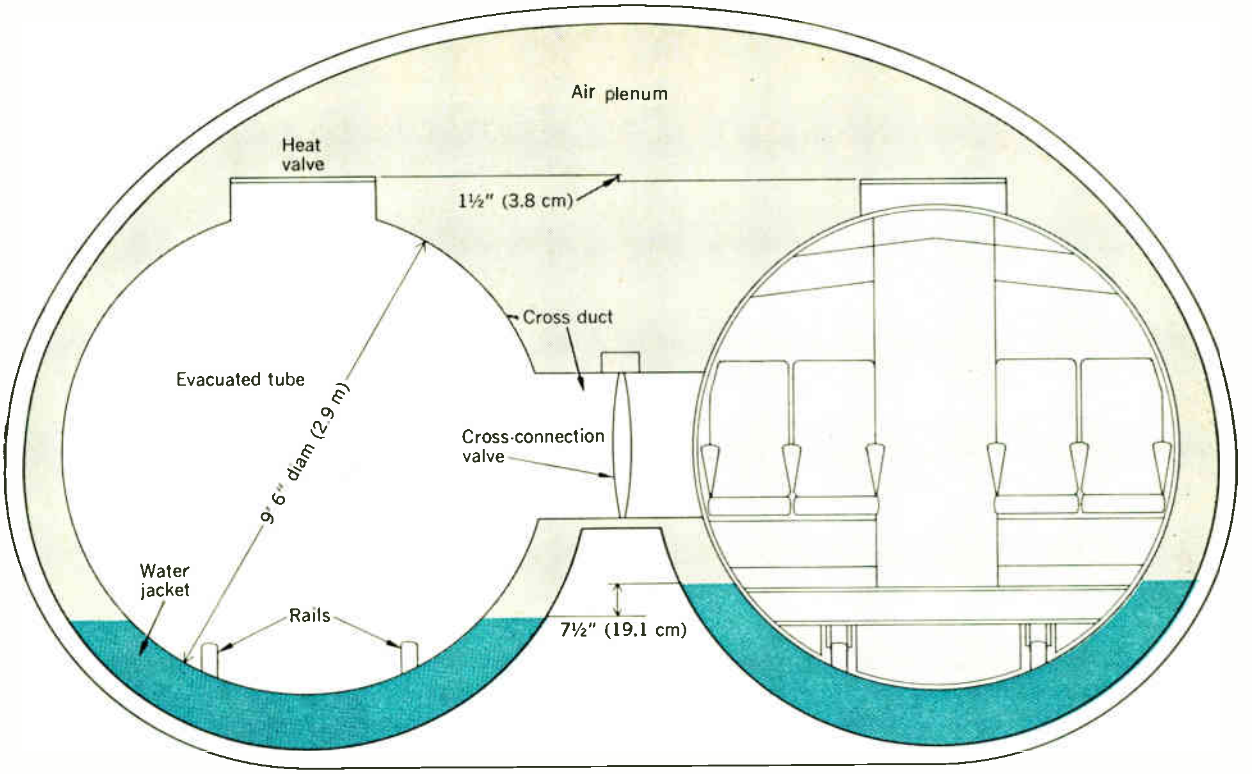


FIGURE 13. Cross section of a typical GVT tube pair. Note that the tubes are floated in water to ensure smooth vehicular travel. The water level in the empty tube is shown at the left; the occupied tube at the right shows the change in water displacement. Note also that cross valves inter connect the tubes, and vent valves, in the top of the tube, open for acceleration of vehicles.

the rigidity and alignment of the tubes. Under train load, of course, the tube will deflect downward. It is calculated, however, that, although the water level in this condition will rise 7½ inches (19.1 cm), the tube itself will settle by only 1½ inches (3.8 cm).

Applications of the GVT system

Although L. K. Edwards, the developer of GVT, and head of Tube Transit, Inc., Palo Alto, Calif., envisions the eventual application of his system to the Northeast Corridor run (Boston–Washington), at speeds up to 550 mi/h (246 m/s), he has also evolved more modest proposals such as . . .

The New York 'supersubway.' Running along a 34-mile-long (54.7 km) twin tubeway, from Mt. Vernon in Westchester County to Huguenot Avenue on Staten Island, with 28 intermediate stops, according to Edwards, would require only 48 minutes. The speed of the tube trains would be about twice that of the conventional expresses now in operation on New York City's subway lines.

Computers would run the train schedules, with headways spaced at two minutes apart, around the clock, every day of the week. At this frequency of service, 75 000 passengers per hour—the equivalent of 25 lanes of automobile expressway—could be moved in a north and south direction.

Edwards says his GVT system could be built at a cost per mile that would be far below that for conventional subway tunneling because:

1. The cross section of the tunnels is almost 50 percent smaller than present conventional two-track subway tunnels.
2. At depths ranging from 90 to 700 feet (30–214 meters) below grade, tunneling would be in bedrock; thus expensive and laborious cut-and-cover excavation would not be required.
3. Gravity and air pressure are used to propel the trains, and costs for power transmission and signal equipment can be minimized.

Old theory, new problems. It must be obvious to the reader, by now, that the GVT concept is merely a sophisticated and updated version of the pneumatic tube systems that have been used for more than 50 years in many large department stores to convey the customers' change and receipts.

As a civil engineer, the writer cannot accept some of the economy claims stipulated in favor of very deep tunnel boring. For example, there would be many construction problems associated with such tunneling in areas of geological faulting, and in the precision alignment required for extra-long runs.

Further, this reporter feels subject to a bad case of the bends—or at least writer's cramp—in contemplating the difficulties of passenger evacuation from the bottom of a vacuum tube, several hundred feet down, in an emergency situation.

R.P.I.'s 'Project Tubeflight'

Project Tubeflight, presently under development by a faculty and graduate student group of aeronautical, mechanical, and electrical engineers at Rensselaer Poly-

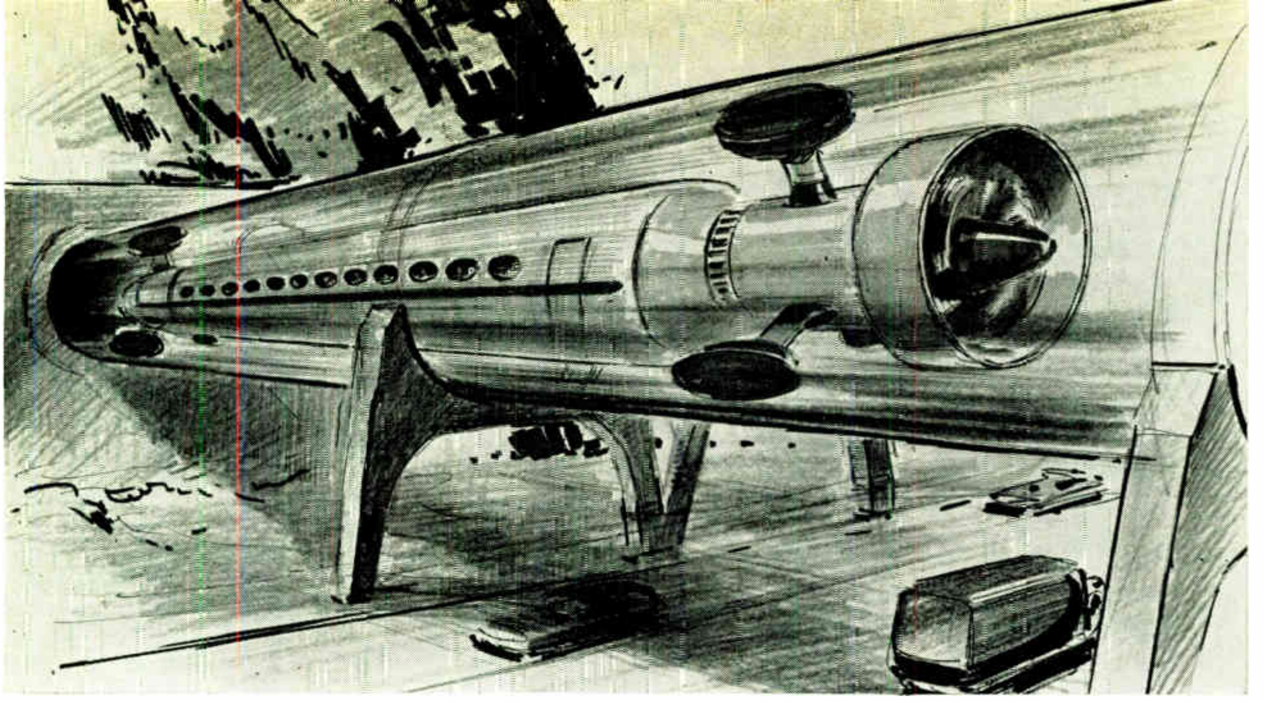


FIGURE 14. Tubes for Rensselaer Polytechnic Institute's Tubeflight system could be built of clear plastic to follow horizontal and vertical curves above grade level.

technic Institute, headed by Dr. Joseph V. Foa, is a practical concept in which aerodynamically supported and propelled vehicles travel at high speeds in nonevacuated tubes. Dr. Foa believes that evolutionary scientific and technological progress in propulsion systems is rapidly taking us away from the wheel as a mode of ground transportation.

Tubeflight differs from the GVT concept in three principal ways:

1. The tubes, or guideways, do not follow a pendulum arc, but may be built above or below grade (Fig. 14) to follow normal horizontal or vertical curves.
2. The vehicles are self-propelled.
3. Subsonic and supersonic speeds are feasible in advanced system applications.

Guideway and vehicular support. In Tubeflight, the air in most of the guideway remains nearly at rest while the vehicles "fly" through. Essentially, the vehicles propel themselves by transferring the air from the front to the rear by means of passages contained within the vehicles, and through the space that separates the car from the wall of the tube. The research team at R.P.I. is presently concentrating its efforts on the development of such an "air gulper" system, which permits air to pass through the vehicles in order to eliminate the piston action of the capsule as it travels within the guideway. Numerous propulsion systems, for the achievment of subsonic and supersonic speeds, are being evolved and tested.

Because of the high speeds proposed for the vehicles, large clearances between the walls of the guideway and the tube cars are necessary. The vehicles can be kept on a centered path by means of suitably arranged GEM (ground effect machines), or air-cushion, pads. In the forward motion of the vehicles, the rearward momentum of the deflected air curtains would also contribute to the thrust. And this type of "floating" suspension, installed in a vehicle with a low center of gravity, would automatically tilt the craft—regardless of speed—to the correct angle of bank in negotiating every horizontal curve.

According to Foa, the presence of large, confined masses of air within the tube would provide a safe and simple solution in braking a vehicle, even at speeds of 2000 mi/h (895 m/s). As soon as the propulsive power input is shut off, the piston effect would take over as the air in front of the vehicle is compressed. This compression could be relieved by vents in the vehicle to permit flow-through control. Once the car is slowed sufficiently by these aerodynamic methods, conventional friction braking techniques could be applied for stopping.

Propulsion systems. Although a variety of power units could be used to propel the subsonic-speed vehicles, Foa believes that a turbofan would be a good engine for this velocity range. The "bladeless" propeller (a Foa invention), however, would probably be better suited for use at higher speeds (see Fig. 15). This device is an application of crypto-steady pressure exchange between axial flows in a liquid or gas.

Supersonic travel would be possible if a more radical engine design, such as a "ramjet," were adopted. A ramjet engine consists of a "nose cone" surrounded by a cowling. When properly designed and operated, air enters the engine through a "leading shock wave" that extends from the apex of the cone to the lip of the cowling. As the air flows around and behind the centerbody within the cowling, it is compressed and mixed with fuel, and undergoes combustion and expansion. In this process, a forward thrust is exerted on the centerbody. If we now assume that the cowling surrounding the nose cone of the centerbody is extended indefinitely to form the tube in which the centerbody travels, we can see an elementary application of the ramjet principle to the Tubeflight concept.

Electric power supply alternative. Dr. Foa concedes that it would be most desirable to power the vehicles by means of external electrical sources. Toward this end, Professors K. E. Mortenson and D. N. Arden of R.P.I.'s

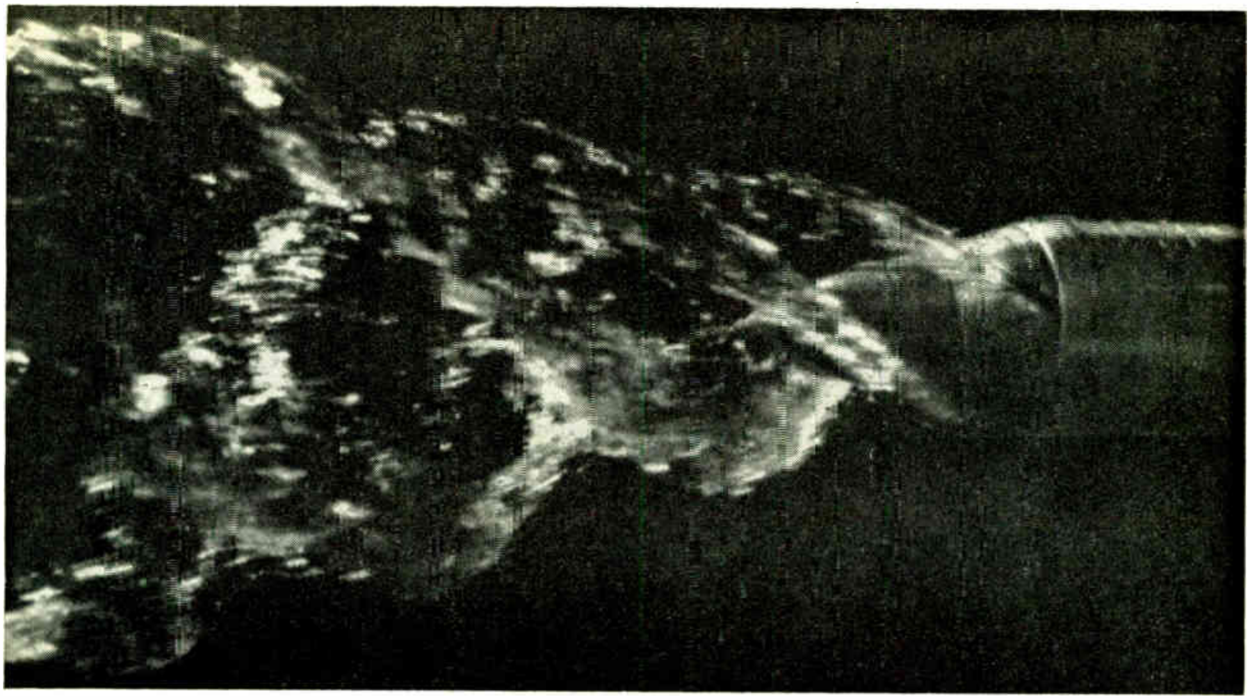


FIGURE 15. The "bladeless propeller," an efficient means of powering the faster vehicles through pipelines. This device is an application of crypto-steady pressure exchange, which provides direct transfer of mechanical energy, and would operate on an air-to-air principle.

Electrical Engineering Department have suggested that a possible solution would be to supply electric energy to the vehicles at microwave frequency by using the tube as a waveguide. Microwave power transmission would have the further advantage of requiring no extra rails or other internal structures. Since most of the equipment would be electronic, it could be situated external to the tube. But since microwave is a line-of-sight phenomenon, many transmission problems in the curved portions of the tube would have to be solved.

Vehicle and tube construction. The vehicles would be constructed of lightweight, high-strength metal alloys. The tubeways for the short-distance, commuter-type vehicles could be built of low-cost clear plastic, and the supersonic version would be stainless steel. In some cases, the pipelines could follow already existing railroad rights of way or the center malls of expressways.

With electronic control devices assisting in the scheduling of the vehicles, trains could be efficiently run over great distances on five- to ten-minute headways. Foa believes that the distance between stations, because of the high speed of the vehicles, would have to be at least 35 miles (56 km).

Running times: highway and tubeway. At present, a motorist driving at the posted speed limit on the New York State Thruway can travel between New York City and Albany in three hours. A Tubeflight vehicle, traveling at a top speed of 500 mi/h (224 m/s) with one or two intermediate stops en route, could negotiate the same distance in about one-half hour. Traveling nonstop, supersonic express vehicles could zip transcontinental passengers—New York to Los Angeles—in about 1½ hours.

The R.P.I. scheme is still in its early R & D stages. Although a 2000-foot-long (610 meters), one-foot-diameter (30.5 cm) steel tubeway has been built to study the dynamics and propulsion alternatives of the 1/18th full-scale computer-monitored vehicles, a full-size prototype seems to be several years away. Tubeflight is still an unfulfilled dream, but it is a dream that is worth pursuing.

The prescription for the future

The world today has the greatest mix of transportation services ever known to any civilization—thanks to the development in this century of the automobile, airplane, and the pipeline. The major problem lies in the practical coordination of these services to provide for the optimum mobility of surging populations and restless people.

And as a recommendation to interested IEEE members, a special issue of PROCEEDINGS, early next year, will be devoted to a comprehensive discussion of all aspects—sea, land, and air—of present-day and future transportation.

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Patterns of U.S. energy consumption to 1980

The importance of energy to the nation's economic expansion and future trends of demand, with special emphasis on the role of utility electricity, are explored

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The total consumption of energy in the United States in the year 1980 is expected to be equivalent to 93 × 10^{18} joules or 63 percent greater than in 1965. Coal consumption in 1980 is projected at 612–677 million tonnes, natural gas at 696 000 million cubic meters, and petroleum products demand at 899 million tonnes. Nuclear power generation will be 723 million MWh; conventional fuel-burning plants will provide up to 1941 million MWh of energy.

The pattern of energy flow is an ever-changing one. Along with the rising trend of total demand to meet the needs of our expanding economy, significant shifts occur in the mix of energy resources supplied to energy markets or consuming sectors. These shifts are occasioned by technological and other factors that influence the size and structure of markets on the one hand, and the supply and availability of specific resources on the other. The result is that in 1967 we have a very different pattern of energy consumption than prevailed two decades ago, and further shifts may be expected in the future.

Assumptions made for the forecast period 1965–1980 provide for no major change in United States international relations; an annual growth rate of 4 percent in gross national product (GNP) in real terms; a growth rate of 1.6 percent in population; stability of the real cost of primary energy resources (relative to each other as well as to the general level of commodity costs); adequate supplies of energy resources, either domestic or imported; and a net foreign trade in energy resources during the forecast period that bears the same proportional relationship to domestic demand for these resources as prevailed in 1965. Other simplifying assumptions are that there will be no major restrictions or curtailment on the use of fossil fuels as a means of controlling environmental pollution; a continuation of an evolutionary technology in the energy sector rather than a revolutionary one; and that no other new fuel sources or energy forms (such as shale oil, tar sand, coal gasification or liquefaction, magnetohydrodynamics, and solar energy) will contribute significantly to energy consumption during the next 15 years.

Energy consumption by source

The nation's energy needs are met for the most part from domestic primary sources of petroleum, natural gas, coal, and hydroelectric power. Less than 10 percent of the requirements are met by imported products; these are mainly crude oil and petroleum. For the next 15 years it is anticipated that increasing quantities of energy will be needed and that by 1980 total consumption will be equivalent to 93 × 10^{18} joules, or approximately 63 percent greater than in 1965.

The combination or mix of specific energy resources required to meet total energy demand will continue to be a function of the separate demands of the major energy markets or consuming sectors (household and commercial, industrial, transportation, and electric utilities). Also influential in the resource mix is the degree of substitutability of resources in various uses, and the forms resources assume within the energy markets as direct fuels, utility electricity, raw materials for chemicals, etc.

In Fig. 1 and Table I, coal is shown as supplying almost half of all energy consumed in 1947; by 1965, coal had dropped to about one fifth of the total. Coal's decline was offset by the expansion of natural gas and petroleum, which together accounted for almost three quarters of total energy consumed in 1965. Historically, hydroelectric power has been of lesser importance in the total energy picture than conventional fuels, whereas nuclear power only recently became commercially viable. During the next 15 years, further shifts are anticipated. Although consumption of petroleum, natural gas, and coal will continue to increase absolutely, these fossil fuels are expected to account for a relatively smaller portion of total energy. The declining contribution of fossil fuels will be offset by nuclear power, which is projected to account for 5 to 9 percent of total energy by 1980. Hydropower is expected to remain stable as a percent of total energy during the forecast period.

A historical supply and demand balance for coal is given in Table II. Recovery of bituminous coal during the early 1960s, after losing most of the space heating and transportation markets, is related to its growing use by electric utilities and expansion of the demand for

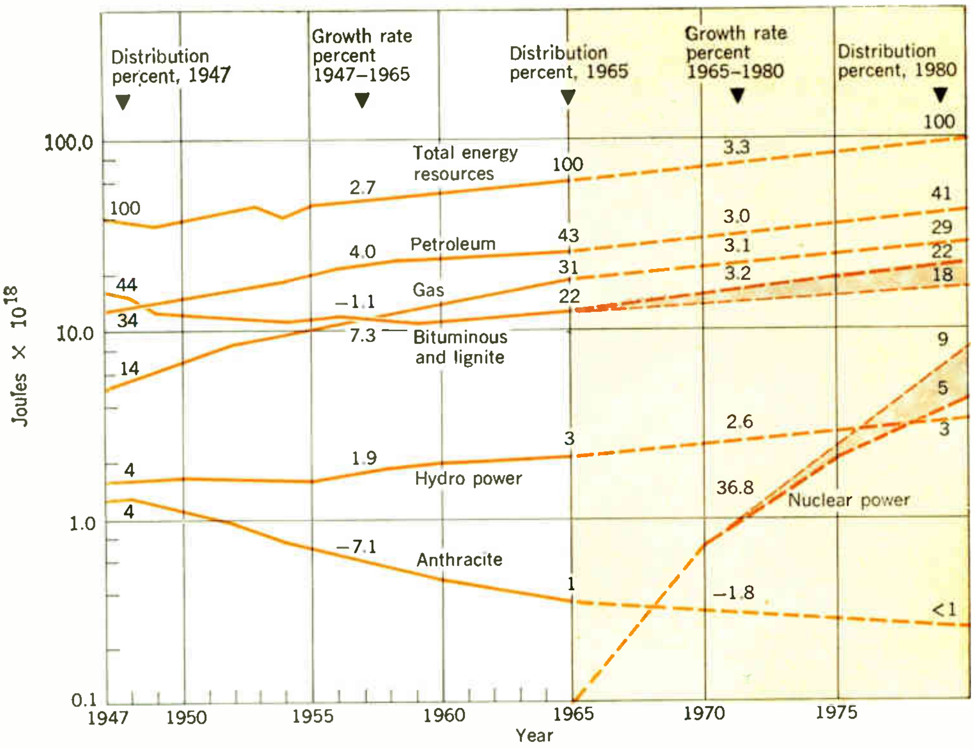

FIGURE 1. Total gross consumption of energy resources.

I. Total gross consumption of energy resources

Item	Quantity	1947	1965	1980	Percentage Average Annual Change 1947–65	Percentage Average Annual Change 1965–80
Gross energy	Joules × 10^{15}	35	56.7	93	+2.7	+3.3
Coal	Million tonnes	550	428	612–677	−1.4	+3.1
Natural gas, dry	Million cubic meters	123 660	450 000	696 400	+7.3	+3.1
Petroleum, including natural gas liquids	Million tonnes	268	566	899	+4.2	+3.1
Utility electricity (net generation)						
Hydropower	Million MWh	85	181	340	+4.3	+4.3
Nuclear power	Million MWh	. . .	4	458–723	. . .	+37.0
Conventional fuel burning	Million MWh	173	872	1676–1941	+9.4	+5.5
Total utility electricity	Million MWh	258	1057	2739	+8.1	+6.6

coking coal. Coal demand is expected to continue to rise through 1980, with consumption in that year projected at a range of 612–677 million tonnes (675–747 million tons). The spread is predicated on two levels of nuclear generating capacity in 1980. Nuclear growth will directly affect the use of coal for power generation, which is projected as 437–502 million tonnes for 1980.

Table III indicates the rapid expansion of demand for natural gas over the last two decades when gas captured large segments of the space and process heat markets from both coal and oil. Approaching saturation of gas substitution in some markets and an anticipated decline in the availability of gas on an interruptible basis at electric utilities is expected to slow the future growth of gas. Demand for natural gas is projected to increase at the rate of 3.1 percent during the next 15 years, with consumption in 1980 estimated at 696 400 million cubic meters (24 600 billion cubic feet).

Petroleum, including natural gas liquids, is the United States' major source of energy. As shown in Table IV, petroleum demand expanded steadily throughout the historical period, and is projected to increase 3.0 percent annually with estimated consumption in 1980 being 6665 million barrels (899 million tonnes). The fastest growing component of the petroleum sector is liquefied gases, which are the major sources of feedstock for petrochemicals; however, the major petroleum product will continue to be gasoline through 1980.

In Table I, net generation at hydropower installations is projected to increase during the next 15 years at the

II. Coal supply and demand (millions of tonnes)

Item	1947	1965	1980	Percentage Average Annual Change 1947–65	Percentage Average Annual Change 1965–80
Production	621	476	740	−1.5	+3.0
Imports, exports (net)	−70.5	−46	−65.1	−2.4	+2.3
Domestic demand:					
Household and commercial	117	20.9	9.1	−9.3	−5.5
Industrial	244	176	152	−1.8	−1.0
(Coal carbonized for coke)	(94)	(86)	(88)	−0.5	+0.1
Transportation	102.5	1	neglig.	−23.1	...
Electricity generation, utilities	81.5	222	437–502	+5.7	+5.6
Raw material uses	5	6	8	+1.0	+1.9
Miscellaneous	...	3	6	...	...
Total domestic demand	550	428	612–677	−1.4	+3.1

III. Natural gas supply and demand (millions of cubic meters)

Item	1947	1965	1980	Percentage Average Annual Change 1947–65	Percentage Average Annual Change 1965–80
Market production	130 000	454 000	712 000	+7.2	+3.0
Imports, exports (net)	−409	+11 970	+18 650	...	+3.0
Domestic demand:					
Household and commercial	30 500	151 300	273 100	+9.3	+4.0
Industrial	68 500	202 000	311 000	+6.2	+2.9
Transportation	...	14 200	19 100	...	+2.0
Electric utilities	10 600	65 500	81 000	+10.7	+1.4
Raw material uses	13 700	8 000	11 800	−2.9	+2.7
Total domestic demand	123 300	441 000	696 000	+7.3	+3.1

IV. Supply and demand, petroleum and natural gas liquids (millions of tonnes)

Item	1947	1965	1980	Percentage Average Annual Change 1947–65	Percentage Average Annual Change 1965–80
Production crude petroleum	250	384	625	+2.4	+3.3
Imports, exports (net) crude petroleum	+6.9	+60.7	+103.4	+12.9	+3.6
Output refined products	259	489	786	+3.6	+3.2
Imports, exports (net) refined products	−7.5	+51.4	+60.5	+11.3	+1.1
Transfers in natural gas liquids	8.7	29.1	49	+6.9	+3.5
Domestic demand refined products:					
Household and commercial	45.2	111.5	137.6	+5.1	+1.4
Industrial	46.3	64.1	96.6	+1.8	+2.7
Transportation	141.5	364	529	+4.3	+3.7
Electricity generation, utilities	10.3	16	18.4	+2.5	+1.0
Raw material uses					
Petrochemicals	3.0	28.0	64.4	+13.3	+5.7
Other	13.5	28.9	53	+4.3	+4.1
Miscellaneous	8.2	12.5	...		
Total domestic demand	268	566	899	+4.2	+3.1

average rate of 4.3 percent per year, with net generation in 1980 set at 340 million megawatthours. Nuclear power generation is projected for 1980 in terms of a range of 458–723 million MWh. The range is predicated on the attainment of either 70 000 MW or 110 000 MW of nuclear generating capacity by that year. Even with the attainment of the high range of nuclear capacity and generation, it is estimated that conventional fuel-burning plants will still provide the greater portion of electricity generated in 1980, from 1676 to 1941 million MWh.

Energy consumption by form

The pattern of energy consumption is influenced by the forms resources are required to assume at the point of consumption, either as direct fuels, raw materials, or utility electricity. The historical and projected demands for energy by form are given in Fig. 2. The direct input of energy resources as fuel is expected to remain the principal form of energy consumption through 1980, accounting for two thirds of total energy utilization in that year. However, although direct use of fossil fuels will continue

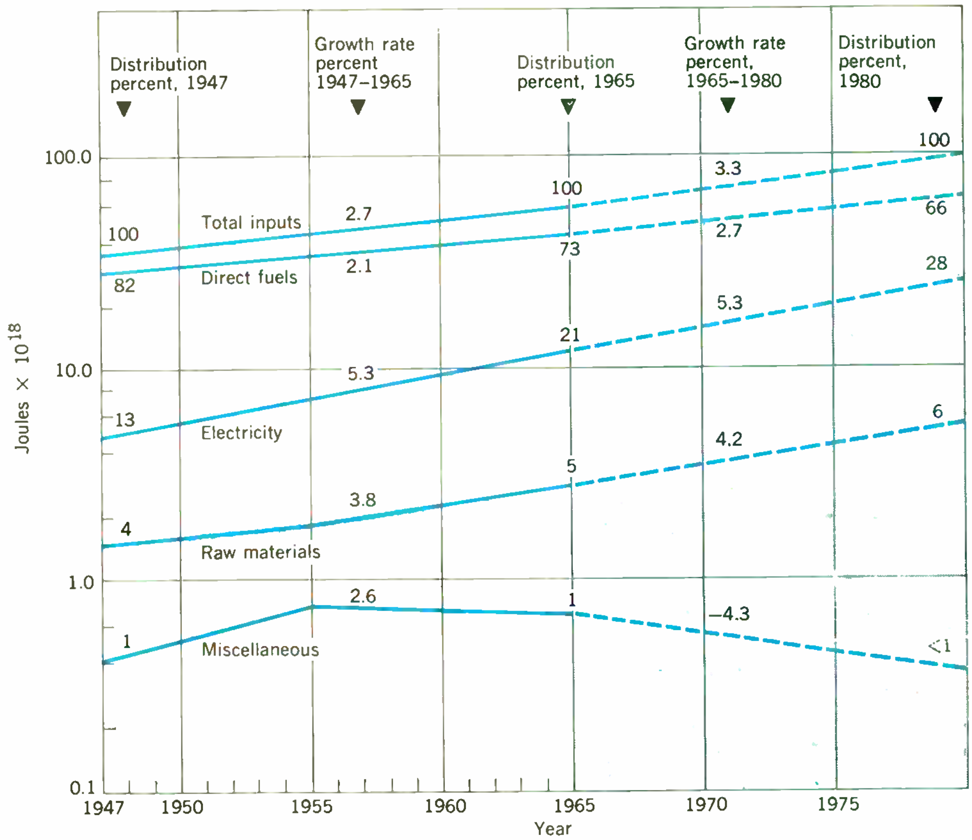

FIGURE 2. Consumption of energy by form of utilization.

to grow absolutely, 2.7 percent per year to 1980, this will be a declining portion of the total energy. Utility electricity and raw materials, the other two major forms of energy utilization, are growing both absolutely and relatively. Raw materials use, which consists primarily of petroleum products, including petrochemical feedstock, is projected to grow at an annual rate of 4.2 percent to 1980 and to account for 6 percent of total energy in that year.

The fastest growing form of energy utilization is utility electricity, which is displacing the use of direct fuels for process and space heating in both the household and commercial and the industrial sectors. It is also expanding rapidly in such nonsubstitutable applications as lighting and appliances, as well as for new uses such as air conditioning. The projected rate of growth of utility generation to 1980, as shown in Table I, is 6.6 percent per year. This is higher than the 5.3 percent growth projected for the calorific value of energy resources inputs into the utility sector for 1965–1980 shown in Fig. 2. The difference in these rates reflects the increase in efficiency of utility generation anticipated for the next 15 years, with fewer joules of resource inputs required per kilowatthour of output.

Energy consumption by sector

The four basic energy markets or consuming sectors are household and commercial, industrial, transportation, and electric utilities. Although still the smallest of the four, the electric utility market has the fastest rate of growth. As shown in Fig. 2, this sector is expected to account for 28 percent of total energy in 1980. In that year it is estimated that 60–71 percent of total utility electricity generated will still come from conventional fossil fuel plants, 12 percent from hydropower plants, and 17–28 percent from nuclear power plants. In analyzing the trends of energy demand in the other three markets, it is useful to distribute the utility electricity to these markets before examining sector trends of energy resource utilization. In this distribution the calorific equivalent of the actual power distributed is used at an assumed 100 percent of efficiency. In Fig. 3 utility electricity is merged with direct fuel consumption in the three markets, and the utility sector no longer appears as a separate energy market.

In the household and commercial sector, combined resource inputs, including utility electricity, are projected to increase at an annual rate of 3.4 percent during the next 15 years. By 1980 this sector will account for 31 percent of total energy consumption. In the industrial sector, combined resource inputs, including utility power, are expected to increase at the rate of 2.7 percent annually, with industry remaining the largest energy consumer in 1980 with 39 percent of total energy. Transportation will remain largely the province of petroleum, and is expected to grow at the rate of 3.6 percent to 1980, accounting for 30 percent of total energy resource inputs within the three markets in that year.

Resource competition and substitution

Competition and substitution among resources within the energy markets are influenced by four factors:

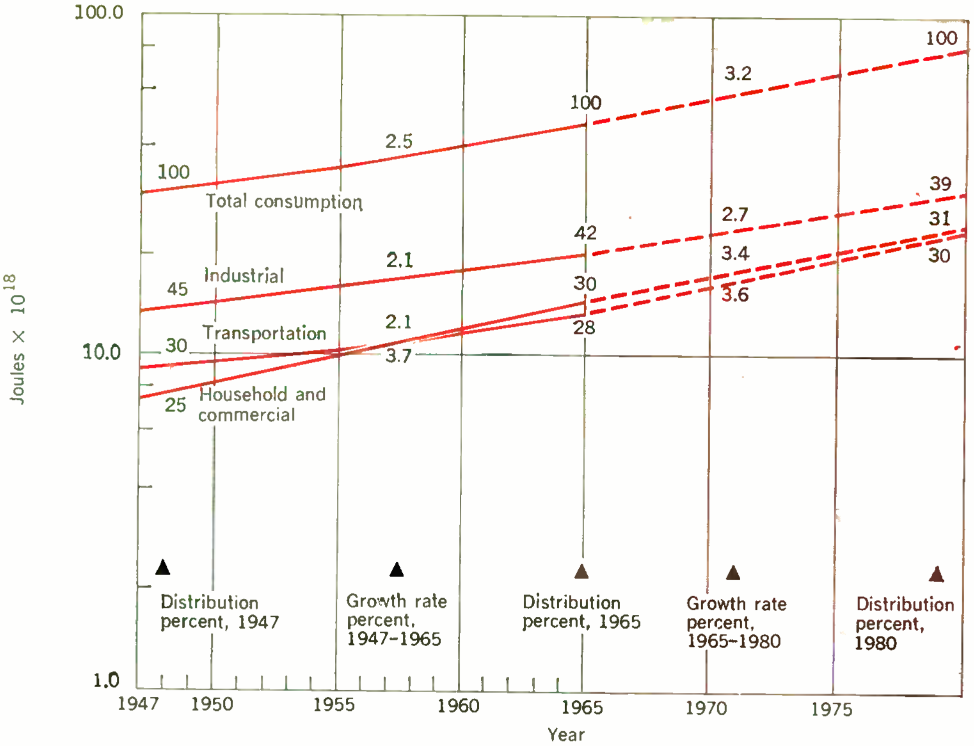

FIGURE 3. Consumption of energy by major consuming sectors.

growth of total energy demand by sector, changes in efficiency of resource use, price changes, and revolutionary technological change. With respect to sector and resources shifts, changes in demand for individual energy resources during 1947–1965 were generally greater than the change in total energy demand within the major markets or consuming sectors. Obviously, the inputs of individual resources within the markets were the subject of pronounced competitive shifts during the period. The extent of resources shifts within the sectors can be seen (Table V) in an examination of the percentage contribution, historical and projected, of consumption of direct fuels and utility electricity in the three major markets, and the resource mix in the electric utility sector prior to distribution to the other markets.

The picture that emerges is one of intrusion of natural gas and, more recently, electricity into the household and commercial and the industrial sectors, and the complete domination of transportation by petroleum. In electric utilities the absolute shift, in terms of quantity, has been much less than the percentage proportional shift, with coal still remaining as the principal source of fuel.

These observed shifts are the end result of a series of complex interacting phenomena. The major factors at work are (1) growth of total energy demand by sector, (2) changes in the efficiency of use of energy by sector, (3) changes in the prices of energy sources, and (4) revolutionary technological change in the consuming sectors themselves or in the transportation of energy.

The effect of the first of these factors on the demand for an individual energy source concerns the structure and size of the markets or sectors wherein resources are consumed, and the growth of these sectors. For example, although the petroleum industry supplies almost all of the transportation market, historically this market has been one of the slower growing of the four primary consuming sectors. However, coal is now finding its major market in the electric utility sector, which has the fastest rate of growth. This differential market phenomenon

V. Percentage distribution of energy resources by sector

Item	Household and Commercial			Industrial			Transportation			Electric Utilities		
	1947	1965	1980	1947	1965	1980	1947	1965	1980	1947	1965	1980
Coal	47	5	1	55	29	20	35	...	...	47	53	55–44
Natural gas	16	41	45	23	41	42	...	4	3	9	22	12
Petroleum	32	40	30	19	22	25	65	96	97	11	7	4
Utility electricity	5	14	24	3	8	13	...	...	...	...	...	...
Hydropower	...	...	...	...	...	...	...	...	...	33	18	12
Nuclear power	...	...	...	...	...	...	...	...	...	...	<1	17–28
	100	100	100	100	100	100	100	100	100	100	100	100

results in differential effects on the demand for individual sources of energy.

The second factor is the increase in the efficiency of use of energy resources within the consuming sectors. This improvement is a result of normal technological advances in the consuming sectors and is comparable to the increasing productivity of labor and other factors of production. In electric utilities, for example, a precise measure of improved efficiency is the heat rate. In 1947 the megajoule input per kilowatthour of output came to 18.0. By 1965 this figure had dropped to 11.1, a decline of almost 40 percent; for 1980 the estimated heat rate is 9.4 MJ/kWh.

With regard to the third factor of price change, traditional economics would assign the major responsibility for shifts of energy source demand by consuming sectors to changes in prices of the energy sources. It is interesting to note, however, that natural gas, which enjoyed the greater gain in market shares among the major energy sources, also has sharply increased in relative price. Despite declining prices, coal still lost its space heat and transportation markets. Price changes, therefore, cannot alone explain the major substitutions that have taken place.

The fourth factor—revolutionary technological change—is distinguished from the "normal" improvements cited in factor 2, and involves major technological changes in the production functions of the consuming sectors or in the transportation of energy. The writers believe that this factor accounts for the major shifts that have taken place in energy demand by source. In the household and commercial sector the major substitution that has occurred is the displacement of coal by gas and, to some lesser extent, by oil. It is advanced that this substitution was largely the result of the growth of the natural gas pipeline network in the United States, made possible by technological innovation of high-pressure, large-diameter seamless pipe. Natural gas is now available in every major U.S. market. The high rates of growth of gas within the industrial and the household and commercial sectors, observed from 1947 to 1965, represent the extension of this transportation network. The forecast to 1980 shows natural gas as growing more slowly than total energy, indicating that substitution from this source has come to an end.

The loss of the coal market in the transportation sector resulted from the dieselization of the railroads, which was undertaken not to conserve fuel cost but to provide more economical transportation. Another example to illustrate our hypothesis is the increase in coordinated electric power networks in the United States, and the growth of extra-high-voltage transmission. This trend is enlarging the marketing areas for large-sized generating plants. Finally, there has been the recent surge in orders for nuclear power plants by utilities, which has resulted in a sharp upward revision in the projected trend of nuclear generation. The introduction of a commercial breeder reactor, for example, could result in another major technological shift.

Conclusions

The essence of our hypothesis is that major technological advance in the consuming sectors normally involves the minimization of cost of the entire production function. Because energy costs are usually low relative to total costs, they normally are not controlling, and technological change can shift energy sources within markets regardless of the cost situation of the energy sources themselves. Thus, technological change is believed to explain most of the historical shifts that have occurred in the energy resources that serve as inputs to the major markets.

Examples of such shifts are the national network of gas pipelines, the dieselization of the railroads, and the extension of the utility electric grid. Major resource shifts engendered by these changes were the displacement of coal by natural gas, and to a lesser extent by petroleum, in the household and commercial sector; the displacement of coal by petroleum in transportation; and the encroachment of utility electricity on direct fuel consumption. More recently, there is the growing challenge of nuclear power to the conventional generation of electricity.

The forecast and conditional assumptions used for 1965–1980 do not take into account further revolutionary technological shifts of the kind described. In addition, the high degree of substitutability among most energy resources makes it difficult to project demand for these very far into the future. Over the long term, the adequacy of particular resources will depend on the future energy mix required to meet the economy's evolving demand pattern.

Until the end of the century, it is generally believed that the energy needs of the United States will continue to be met primarily from fossil fuels, with a gradually increasing contribution from nuclear power. Natural gas and crude oil production are expected to peak about the year 2000. This peaking will be occasioned as much by cost as by possible reserve deficiencies.

Because of alternate sources, a potential scarcity of liquid and gaseous fuels from crude petroleum and natural gas is not believed to constitute a serious long-term supply problem in energy. As reserves of conventional fuel sources become less abundant and more costly to find and produce, the relative economies of synthetic liquid fuels or gas should improve. Examples of these are substitute sources such as shale oil and synthetic liquid fuels from gas or coal. Also, as the liquid and gaseous fuels increase in cost, they tend to give way to other competitive forms of energy use—notably electrification. The electrification of railroads and highways, including the electric car, is being studied, and such concepts as the all-fuel or all-electric economy are no longer considered as wild as they once were. New energy sources or conversion methods now in the experimental stage include the fuel cell, magnetohydrodynamics (MHD), fusion, thermoelectricity, thermionics, and solar energy. Improved methods of power transmission include the use of direct current in extra-high-voltage transmission over long distances.

It is our contention that further revolutionary technological change is inevitable. Such change, along with the lesser impacts of market growth, increasing efficiency of resource utilization, and price variation, will certainly affect the future pattern of energy consumption in the United States and lead to further shifts among resources.

This article is an updated condensation of a paper, "Patterns of Energy Consumption in the United States, 1947 to 1965 and 1980 Projected," presented at the Tokyo meeting of the World Power Conference in October 1966.

Human enhancement through evolutionary technology

The coming widespread availability of computational power or "distributed intelligence" could open the door to a new kind of "interfacing in depth" between men and machines. Engineers might begin designing evolutionary artifacts aimed at an enhancement of man's control skills and perceptions

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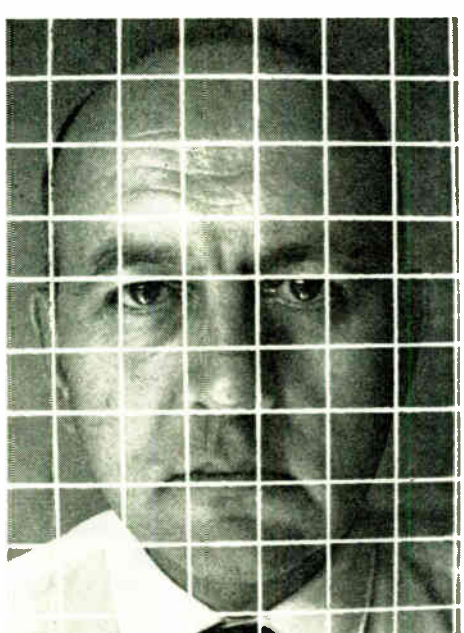
The thrust of this article is this: There is a need now, more than ever before, for men to stretch their capacities in what we shall call evolutionary skills. Moreover, it is at last becoming possible technologically to enhance these skills in man by incorporating somewhat similar evolutionary skills in the machines which we design and build. However, if engineers are to develop machines with evolutionary capabilities, they will need to restructure their own way of thinking, throw out traditional ways of thinking, and find their way, through playing with evolutionary design techniques, into an ever-deepening understanding of the significance of such techniques. They must bootstrap themselves into a new kind of "think," into a new climate of man–machine interaction, in which men evolve intelligent machines and intelligent machines evolve men. This new kind of think is what this article tries to unfold in an effort to spur lively support for the evolutionary direction.



It should be clear from the outset that a widespread technology of artificial intelligence, upon which the argument of this article depends, does not yet exist. Some readers will hold that it is wrong or premature to extend new promises and proffer new uses of intelligent machines when the field is still littered with the disappointments and the disparities of past promises and present performances. But if intelligent machines and an evolutionary technology are to come into widespread use, there must also arise a widespread realization of how that technology might profitably be used. To reinforce the demand for the technology, we need a spirited and practical image of the ways in which it is needed.

"Human enhancement," as we argue in this article, is *one* way. It is a way of involving the human in the evolving technology. It is a way of breaking the paradox: "You don't get the technology until you have the demand; and you don't get the demand until you have the technology." Both the demand and the technology must evolve hand in hand, through a real-life dialogue. One way to get this dialogue going in an evolutionary direction is to do a bit of skating on thin ice. That we shall do.

The context

Times change, and the works that men do change. Through invention, and the evolution of inventions, man has continually modified and worked shifts in his environment. Each generation adds its creations to what came before. Field becomes farm, logs become wheels, rocks become buildings, the shortening and lengthening shadows cast by the sun become time. Each of these transformations dawns in the mind of man in the form of concepts, ideas clenched in the mind "like a fist in your hand."[1] Man envisions his world in the light of his own works . . . "the pastures of heaven," the great "wheel of the universe," the "house of the soul," the "desire for immortality." And as man's invented artifacts give way to new inventions, his conceptions of the world give way to new concepts. Yesterday's truths become today's clichés, the mental junk and obsolescent concepts that need to be continually cleaned out to make way for new truths and new concepts. In the Western World, science is born, and psychology springs from Aristotelian analyses. As Eilhard von Domarus tells us in "The Logical Structure of Mind,"[2] it was Aristotle "who made possible the distinction between the sciences of mind and of matter"—two branches of science that have been separated ever since. In our own epoch, man conceptualizes *evolution*, and begins to examine the deep laws of life whereby the past has passed into the present. The farms have become highways, the wheels have become automobiles, the buildings have become laboratories, and time has become relative. And only in our day do the scientists of matter and of mind attempt to

bring the two houses of science together again, to crown these fantastic edifices of knowledge that have been two thousand years in the making.

But with what success? It begins to appear that the logic that applies to the analysis of inanimate matter, a two-valued logic of true-and-false, and the chains of cause-and-effect, do not aptly model the operations of living beings. The description of life requires more than a logic that can be derived from "truth tables."

Unlearning

It appears, too, that inadequate attention to the process of cleaning out mental junk, of unlearning obsolescent concepts, hinders the evolution of new concepts. Yet, we don't even know how to think our way into the problem of how we "unlearn." Our newest computational tools, however, invite us to reconsider basic premises about how we learn to learn.

In tracing the evolution of man's inventions in his book for Everyman,[3] Norbert Wiener, the creator of our legacy of cybernetics, notes that "the art of invention is conditioned by the existing means." Today, as we well know, the "existing means" have changed radically from the means of just a generation ago. The dreams of our predecessors, and their purposes, have become *our facts*. Many of the potentials that Norbert Wiener put forward only speculatively are already here. Many of his conceptions exist as our hardware, and these new tools are getting better at a *rate* he more or less predicted. His book, published in 1950, although it already reads like a "period piece," can now be profitably re-evaluated by the community of engineers as a source book of ideas of how to make practical use of our new computational and technical skills. The title of his book, *The Human Use of Human Beings*, still lingers as a call to action rather than denoting an accomplished fact.

The new means

To do what? To create, through the emerging means, through distributed "artificial intelligence," an environment more consonant with the real needs of man. There will soon be a computer available at the end of each telephone circuit that could be used to help prevent us from being carried beyond our human powers to manage an environment increasingly dominated by unintelligent machines governed by essentially nonhuman principles. We need an environment, which is more and more made by us, to have more of our kind of intelligence and our kind of behavior. But how can that be done, and why should it be done?

In his inaugural address as President of M.I.T. this past October, Howard W. Johnson affirmed that Institute's concern with the vigorous current of change that modern technology is producing. We cannot produce students who are, as in Kafka's words, like "couriers who hurry about the world, shouting to each other messages that have become meaningless." It is difficult to see, he stressed, how the evolving professional community can be without an "understanding of [both] the physical and biological world."[4] Furthermore, he quoted President Kennedy in stressing that "the real problem of our century is the management of an industrial society." Can engineers use their technological skill to refine what has been seat-of-the-pants intuition? How can they assist in and clarify the tasks of managing an industrial society?

From another quarter of our social organization come similar sentiments: "Developing our human capabilities to the fullest is what ultimately matters most. Call it humanism—or whatever—but that is clearly what education in the final analysis is all about."[5] The speaker is Secretary of Defense, Robert S. McNamara. Again, there is the practical question: how?

Perhaps, as we have already suggested, our present technology already contains within it the kernel of the answer to all these questions. Some engineers and others believe that technology cannot find solutions to the social displacements caused by technology. However, the reverse might actually be the case. The solution might come only through the technology.

Accelerating ecological imbalance

Our argument is relatively straightforward. It revolves around the historical fact that man has tampered with natural evolution to a spectacular degree. Man has been so successful in his efforts to control his physical environment that he has usurped nature's role in maintaining a kind of balance among all its parts. Humankind has altered the natural ecology and has started to organize things in its own way. Man, instead of being a subsidiary animal in the grand design, has become, for all apparent purposes, the driving element in the natural system. But the trouble is that man has not yet become such an accomplished systems engineer that he can master and maintain a more or less stable planetary ecology on his own terms. There are insistent signs that man, through his great engineering works and his technology, threatens to throw the naturally balanced system into a violent instability. The air and waters of the planet are being rapidly poisoned, many resources are being depleted, the available space is rapidly being occupied by man and his inventions, many unfortunate men are at wit's end, and so on. Thus, there is a pressing need, not just for conservation, but for a new level of stability and control in this dangerous evolutionary trend.

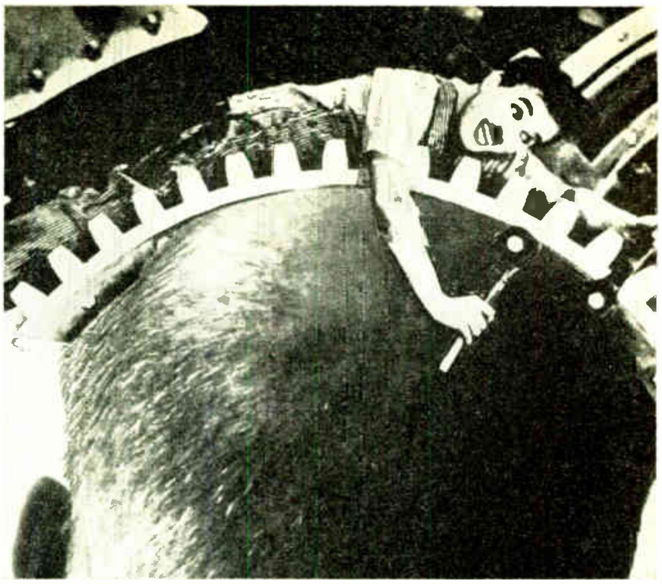
The automation of industrial man

On the other side of this issue is the fact of man's own existence, and whether or not he has liberated himself through his efforts at control over his environment. There is the question of whether, in his increasing development of automatic machines, man has not also automated himself, and seriously reduced the potential variety and richness in his own life endowed to him through his biology, through the gifts of millennial evolution.

Evolutionary technology

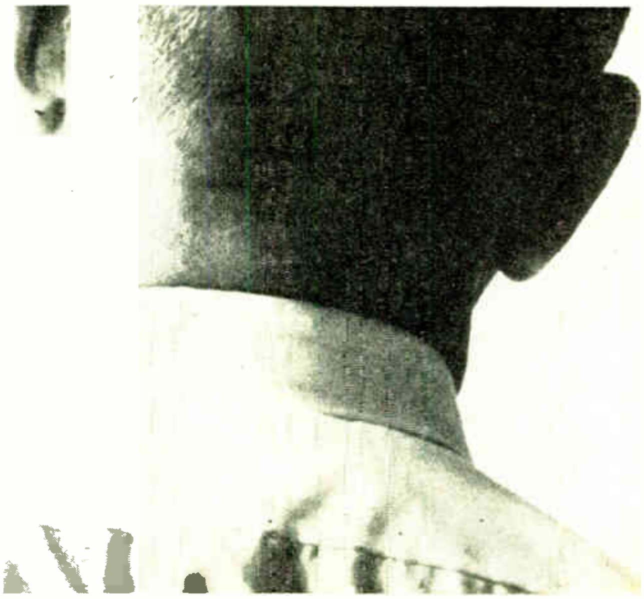
It is our assumption that all of the suspicions put forward in the foregoing paragraphs are manifestly true. Our massively successful technology, which was supposed to have provided our salvation, has brought us into deep trouble. We postulate that this technology must be modified in a dramatic fashion, that our machines must be provided with evolutionary powers, with some intelligence more like our own.

We shall have some fairly specific strategies to put forward that touch on many levels of the same problem. Moreover, our ideas are aimed at engineers, for they are as cognizant as anyone about how much machines now control our environment. Furthermore, through their excellent work in the past, and through the work they are doing at present, engineers have brought within reach the possibility of endowing machines with evolutionary skills, which should not only bring about an enhanced technological effectiveness but human enhancement as well.



However, despite their awareness of their machines and the nature of physical control, there is a serious question as to whether or not engineers have properly conceptualized the breadth of the effects that machines have had on human life. Machines could be set up and designed so as to teach their users how to use them more expertly, so as to enhance both the control and conceptualizing skills of their users, so as to satisfy the user's own personal needs and his own personal style, rather than, as it is now, so as to reduce individuals to a stupefied norm. What we are after, in engineers, is a new respect for the capacity of our new control technology to serve the individual and his individual variations. A regard for individual variations, in the designing of new machines, is necessary for the evolutionary process.

The notion of evolutionary skill has many ramifications. Both man's control and conceptualizing skills are more culturally determined than we ordinarily realize, and are



not being used to their fullest potential. Furthermore, these skills, controlling and conceiving, are less separable from one another in an individual than the separate terms suggest. One begins to gain control as he conceives that the possibility of control exists. We are only now becoming aware of the need for personalized environmental management. This brings a new perspective: a man is constantly changing, either growing or decaying, just as his environment is constantly changing. Exactly how a man grows and changes, how he evolves in his powers of control and communication in relation to a changing environment, must be analyzed and described through some formal means. As yet, no such formal or scientific description exists, but it now appears possible, through the use of modern tools such as the computer, to begin to develop such a formal description, and to begin to explore man's potential for the enrichment of his control and conceptualizing skills.

But we won't know exactly how to approach this new description of man until we perceive how man has learned over the generations to solve real survival questions, often without awareness. Our methodology, our approach to the restoration of natural-like ecological controls, must grow out of data from evolutionary real-life situations. Such data must emerge from a "dialogue," a kind of interfacing in depth, between man and his new machines.

Complexity and measure

With physical systems of the order of complexity of a man, or with large systems made up of many men, with systems as large as our human society, which are now composed of complex aggregates of men and machines, it appears no longer possible to analyze or simulate the behavior and systematic requirements through traditional modes. Their operations and functions, involving multifoliate nonlinear feedbacks and interactions, are far too rich for the usual descriptions we apply to physical systems. Units of measure for functional controls relevant to a particular purpose are fundamentally different from the units of measure ordinarily used for describing the actual construction of a system. With truly complex systems, one seeks out simplicities of behavior rather than simplicities of construction, because such systems have complex choice patterns with which to stabilize themselves in relation to dynamic environments. The problem is to find those measures that allow one to simplify the necessary control behaviors.

But up until now we have not sought a formal methodology for finding such measures. Thus, to begin the construction of evolutionary systems, it may be necessary for us to try them out, to build the physical systems so that they can "evolve" through real time in real-life situations. It is quite possible that through such evolutionary designs, new types of systemic "simplicities" will be discovered that ordinary analysis would not make evident, or that are not apparent in the complicated aggregates of smaller systems of the kind that engineers have been studying up till now.

Planning for unexpected applications

The introduction of an evolutionary system into a real-user situation is colored by a difficult question that will affect any organization's deliberate decision to move toward the incorporation of such systems into real-time operations in which the usual daily activities continue. The question is how to justify the cost of an apparatus or procedure whose functions and virtues in terms of the purposes of the organization cannot be wholly defined in advance, but where it is a reasonable gamble that the "unexpected" will be profitable. For instance, many organizations have been using conventional computers, but they have no way of knowing whether or not they need or could use the more expensive on-line time-sharing systems now being evolved, since they have had no experience with such systems. The problem then for the person who believes in the real value of such a system is to get the potential users involved in it, to get them to grow with it as the machine–software combination is evolved to their purposes and style. If the users become involved in a prototype scheme of the system that is capable of being evolved in its usages, then the procedures of the humans change along with changes in the procedures of the machine. But the allocation of many of the costs in such an evolving system, in which the user and software procedures are undergoing "tuning" to one another, cannot be stipulated in advance. Despite the difficulties of incorporating evolutionary systems in real-life situations, it should be evident that this is the only way their true worth can be discovered. A prototype must have sufficient complexity to begin the evolutionary process and sufficient flexibility so as not to preclude unexpected possibilities or benefits. Much of the physical system can be specified in advance, of course, as can be the system software (the available programs), but the users will not know beforehand, in depth, *all* the things that they will be able to do with it.

Also, with very complex machines, if the machine does not help the user by evolving and enhancing his initial capacity to control it, he may simply reject it as being useless; and he may continue to use, at great cost, obsolescent and perhaps even dangerous machinery with which he is familiar.

Control of complexity requires machine intelligence

From an engineering point of view, it is rational to ask at what point systems become so complex that traditional methods of attack become inadequate. It is said that the dividing line, where the capacity either to analyze or simulate a system breaks down, is somewhere between the complexity of a supersonic transport and a huge computer network. The flight dynamics of the SST can still be simulated, but when you go to an information network with many users, the simulation becomes meaningless. Somewhere between these orders of complexity, traditional methods will break down completely. Perhaps with telephone systems, certainly with large time-sharing computer systems, on out to large sociological units, you have passed a break point after which you must go to a new methodology, to an evolutionary method of attacking the system problems.

However, our interest and emphasis in evolutionary design, although it has something to do with the "practical problems" of gigantic systems, is not focused on such questions. Our interest in evolutionary machines is based on a concern for what has been happening to the human users of machines, what is now happening to them, and what is likely to happen. We see evolutionary machines of all kinds, large and small, as large as time-shared computer systems or as small as chairs, as a prerequisite for what we shall call "human enhancement."

It is precisely this quality, built in advance into a system, of man and machine being able to evolve each other, that we consider vital to solving the problems of technical pollution discussed earlier.

The need for new concepts

In effect, we are saying that our present tradition of science and technology, the physical science built up so manifoldly of sequential cause, then effect, relationships, has brought us to a kind of dead end. Something radically new is wanted. More refinements of cause-and-effect, stimulus-response models, or more aggregates of such models in complicated systems, are not likely to lead to any real amelioration of the technological pollution.

For instance, highway engineers design and build big new highways to alleviate existing patterns of traffic congestion. They pinpoint the bottlenecks existing before the new highway and attempt to bypass them. But the construction of the new highways and bypasses, causing displacements and disruption to humans and animals through the leveling of trees, individual dwellings, farms —all this destruction and construction is barely complete before the new highway itself becomes obsolete. Change evolves change—even if we blithely deny the need to research the process.

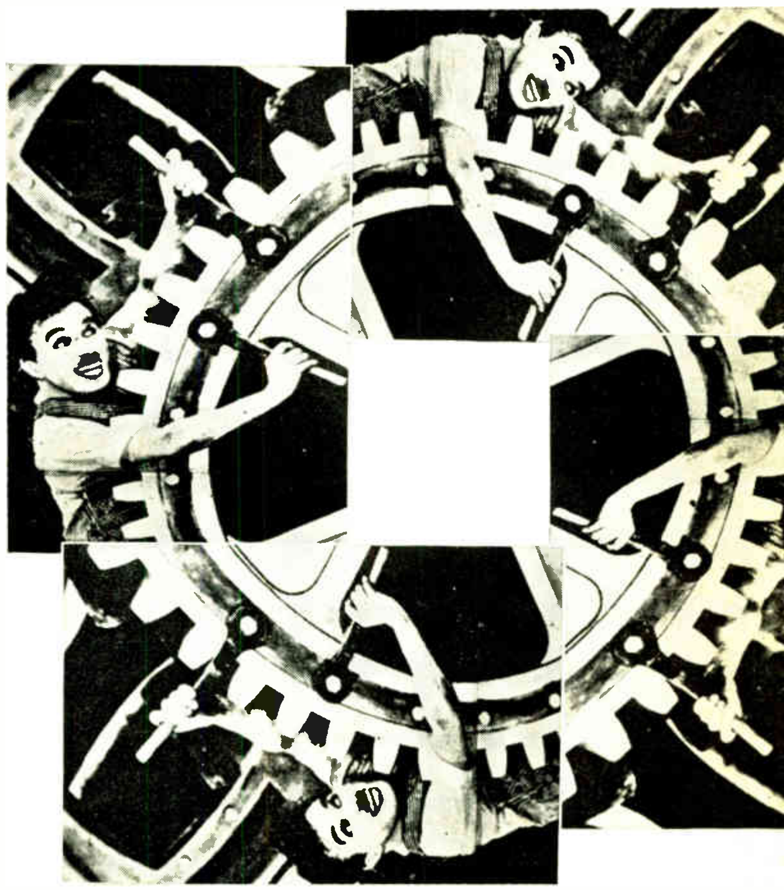
If, as Oliver Selfridge of the M.I.T. Lincoln Laboratory suggests, these problems cannot be left in the hands of traffic engineers alone, then who are the people with a broader grasp? The governors of the states? They too are hampered by legal codes and political structures that are also obsolete with respect to their capacity to respond appropriately to the massive social effects of technology. The tendency in the highly developed countries, such as the United States, is to look to the highest levels of the government for solutions to the problems manifested at apparently local levels. But even at the highest levels of government, there exists an uncertainty. We do not know where to allocate decision skills that can effectively increase our responsiveness to the social ills caused by technology. Something new is needed.

Irrelevant truth

To get moving toward this "something new," we must begin to shake ourselves out of the old. This is not easy. It is not even possible to gauge how deeply our classical concepts *are* rooted, until *after* we have adopted the evolutionary viewpoint that regards information as continuously being evolved from the unknown, metabolized into meaning, and finally recontexted into noise. Truths, while still true, become irrelevant. Man survives as a creature who continually changes and evolves, a creature who feeds on novelty, who reorganizes himself as he reorganizes his physical world and maintains stability by this process of change. It is not easy to adopt the evolutionary viewpoint, or to bring it to bear relevantly in engineering work. The old Greek way of simplifying the physical world into timeless true–false statements is what we have cut our conceptual teeth on. New information or insights we receive, any novelty we detect, we will automatically try to structure and fit into our present conceptual framework, so that we must suffer the frustrating effort of trying to "see" something outside the framework as though it existed within the framework. When we cannot make the fit, the world seems out of control and absurd, but it is our old Greek concepts that are absurd. We have informal ways of getting around these absurdities; but they are not codified for ready use or teaching.

Points of view

Man's irrepressible need to explain away or to fit new experiences into his existing conceptual framework often enough leads him into making comic connections, one of the most delightful of which is mentioned by Freud: "On one occasion during a sitting of the French Chamber a bomb thrown by an anarchist exploded in the Chamber itself and Dupuy subdued the consequent panic with the courageous words: '*La séance continue.*' The visitors in the gallery were asked to give their impressions as witnesses of the outrage. Among them were two men from the provinces. One of these said that it was true that he had heard a detonation at the close of one of the speeches but had assumed that it was a parliamentary usage to fire a shot each time a speaker sat down. The second one, who had probably already heard *several* speeches, had come to



the same conclusion, except that he supposed that a shot was only fired as a tribute to a particularly successful speech."[6]

Somewhat less amusing, but revealing nonetheless, are the kinds of "in" jokes perpetrated by students of engineering and science, who find it funny to talk about the "real" world in terms of the equations and physical laws they are learning in their academic courses. The humor lies in the fact that "everyone knows" that these formulas are absurdly far from explaining the real world as they already know it from their experience. But give these engineering students a few more years of exposure to these technical formulations, and the constrained world technology, demands an ever-higher responsiveness on the part of those who attempt to manage the change as well as those who merely try to adapt to it as best they can. The slowing of children's learning to an adult teacher's polite pace is no longer advantageous. The manual workers, who acquired a fairly narrow repertory of skills, were the first ones to be threatened with obsolescence, but now even the clerical and conceptual workers are being overtaken by their technology. The refreshing creativeness of children must be allowed to reap its fruit in enriched variety of styles and interests and ways of knowing. The old kind of standardization has lost its utility.

Man-machine dialogue

What has all that to do with dialogue? Imagine, if you can or will, a machine that is as responsive to you as our postulated tennis teacher—a machine that tracks your behavior, that attempts to teach you a new control skill or a new conceptual skill and gives you cues as to what you are doing wrong. Furthermore, the machine gauges how far off your actions are from the program you are trying to learn, and "knows" the state of your perception; it is able to "drive" your perception gradually and

sensitively, pushing you into unknown territory, into making you feel somewhat absurd and awkward just as you do when you are learning those new tennis movements. Suppose, in fact, this machine could sense factors about you that even a human instructor would miss—how your heart rate was changing its acceleration, how your temperature was rising or falling, how the acid production of your stomach was beginning to increase, or how your eyes were actually tracking during certain tasks. If the machine could use these "sensory" inputs in an intelligent fashion, it could be even more responsive to our needs and problems than the tennis instructor. In other words, this supposed machine would functionally be what we call a "gifted teacher." This machine would be behaving, in fact, like a deeply perceptive wise man who can behave in such a manner as to drive us out of our resistances to learning new patterns of behavior. He would be "tracking" us in the complex of our physiological and mental behavior. And he would not only be tracking, but he would also be deftly pushing, rhythmizing his interventions to our "natural" time scale so as not to push us over into radical instability. This wise friend would not be reading out to us archaic laws, set in a language that is irrelevent to our needs and purposes (that would be just a smart friend). He would be sensitively following our natural responses, building them by gentling their cadence just beyond the pace on which they evolved a moment before, and through this guidance, he would enhance what we could see and feel and do. What was mere noise or disorder or distraction before becomes pattern and sense, information has been metabolized out of noise, and obsolete patterns have been discarded. The man who helps us sense *our* wisdom we call wise.

Nondialogue interfacing

Granted, such a remarkable machine does not exist (except as a twinkle in the imaginative eye of a father who is trying to conceive of his infant son's world). By contrast, consider our actual machines, the ones we have been building since great-grandfather's time. What is the character of our dialogue with such machines, and what has this dialogue done? As ingenious as our machines have become, our dialogue with them is essentially unidimensional. We read meters, push buttons, throw switches, or maneuver a control stick. In a car, we sit relatively immobile while we turn a wheel either clockwise or counterclockwise. And so on. Some of the photographs on these pages suggest how narrow our contact is with our present machines, and others suggest a new depth of contact. The significance of our present machines for us is that these machines also condition us to certain limited behaviors. They do a lot of the dirty work for us, but they make us pay a price in their management. Our machines are "stupid"; we cannot engage in a rich dialogue with them. Their management stupefies us, for we must adjust ourselves and behave in a more automatic fashion. We have learned to live by the fixed machine time—three shifts a day of tending machines—rather than following our natural time. The machines follow fixed laws and, in managing them, *we* follow fixed laws. Not only that, but all men who manage machines must manage them in more or less the same way; all men are constrained to be "average" men vis-à-vis the machines.

Moreover, as our machine systems grow more complex, stretching their wires and tentacles throughout the fabric of our human society, the danger of their carrying us out of control becomes more magnified. Regional power failures make us aware of our dependence on machines and, according to the news, of our joy at their embarrassment. The danger of machine-like decisions being made by the aggregates of existing machines, made through a modal logic which is not *our* logic, persists. For instance, the Internal Revenue Service simplifies *our* affairs to meet *its* programmer's problems. We require large systems with which we can engage in humanlike dialogue, of the rich kind that occurs between people. Our entire machine environment needs to be given a self-organizing capability that is similar to the self-organizing capability of men,[8] so that both kinds of systems can evolve and survive over the long run. Coexistence is better than the slavery to the stupid machines that is accepted now.

But can sensitive capabilities be given to machines? Will it be possible to create a more intelligent and more responsive environment? Or are these merely fanciful and empty wishes? No. Work is already beginning, and we shall cite some examples in a subsequent article.

Dialogue specifications

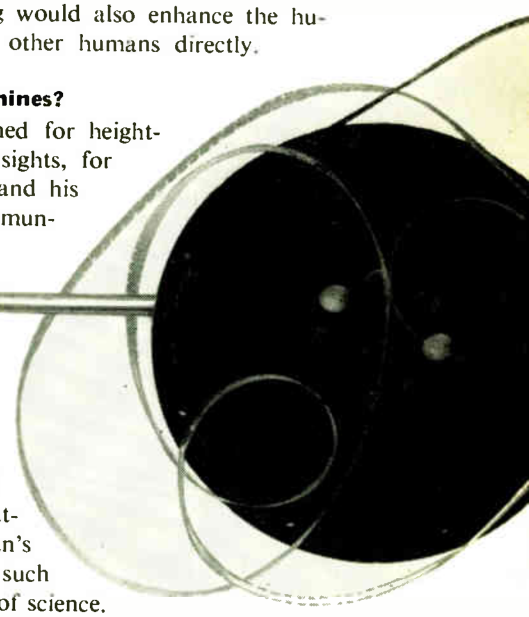
We should summarize in a little more technical fashion some of the characteristics of dialogue systems: (1) A dialogue has the capacity to draw its participants beyond the sum of their action or intent. It evolves them. (2) The dialogue occurs when the two or more systems (e.g., persons) begin playing each other's transitional states simultaneously. They predict and hold a high level of what will be novel, given these predictions. Imagine yourself with a well-matched friend. You will also try to keep fresh and unexpected information building if you are close. You will drive the dialogue almost to the point where you are not sure that there is understanding until you test. Both parties push their individual codes just to the edge where there is just enough common coding to comprehend one another if their "prediction" is right. (3) Each participant uses less ambiguity when he perceives that such a reduction is needed (either because the other person is obviously not understanding or because there are environmental distractions—the time delay before such correcting is itself a code). (4) Error correction and an evolving purpose are used to control the conversation and allow the conversation to develop. (5) As the dialogue drives its participants, the self-regenerating power organizes its components even as the whole system changes, and some components waver on the limits of instability where the lack of prediction and the delicacy of balance allow what has been noise to become organized as a controller. Noise acts on the system when it is easily perturbed and the resultant shift reflects this effect, and what happens becomes information (thus, for instance, when a person is irritated or abnormally disturbed, he does things that do not follow his "normal pattern," and gives the other person an insight into his underlying operating codes). The system must be time-phased. It adapts to environmental change in shorter and longer intervals, the variance in inertia preventing fragmentation. (6) Automatic error correction allows the system to remain within required limits for smoothly evolving, giving dialogue a purpose. The dialogue of seminar learning has a different purpose than, for example, lecture teaching. The power of dialogue is commonly used to create data out of noise, to create information out of what was so unknown (and perhaps unsuspected) as to be beyond that which was perceived. It is used to give fresh conceptual hooks without which data would be so meaningless as to be beyond perception. During dialogue, a pattern emerges from what was meaningless and random. This is what real learning and unlearning (destructuring the obsolescent concepts) is about.[9] Thus, (7) in dialogue, the changing in entrainment of many levels of synchrony and isomorphism allows significance to grow out of the slightest variations that happen at a control point—a point where a small change makes a large difference in the way the total organization goes. In dialogue, there is continuous identification of those points where slight change will induce significant new recognition of pattern. That is why the amount of information that can be exchanged is of a higher order than in nondialogue systems—a considerably higher order.

In sum, the most delicate matchings of stages so that two systems (either man-and-man or man-and-machine) communicate optimally for the purpose of unlearning conceptual and control obsolescence will occur during the dialogue.

As McCulloch and Brodey phrase it, "dialogue is not a simple alternation of active speaking and passive listening turn by turn. Both partners are continuously observing and sending many cues. It is a closed loop of many anastomotic branches through which there runs at a split-second pace an ever-changing symphony and pageant relating man to man ever more richly."[1]

Dialogue: formally obscure, operationally familiar

Thus, if men are to use machines for learning, they must see that these machines incorporate the capabilities of evolutionary dialogue in order to enhance the possibilities of enriched information exchange. It is even conceivable that in dialogue with machines, man may discover prejudgments and preconceptions that are so omnipresent with men as to render them utterly automatic. If this is indeed the case, the way could be opened to modeling and discovering the deepest laws of man's learning behavior, thus also opening the door to making teaching a science rather than an art presently enjoyed only by the gifted few. If education's purpose is indeed human enhancement, then such man–machine education would be human enhancement par excellence. Such heightened teaching would also enhance the human's capacity to teach other humans directly.



Why dialogue with machines?

Man has always yearned for heightened perceptions and insights, for the truth about himself and his world, and for deeper communion with his fellow men. The drive for man to model or map in his own mind the nature of life and of the physical world is virtually automatic, and seems related to man's survival. The drive for such knowledge is at the heart of science. In some periods, men have sought heightened perceptions through starving themselves, through living alone in desert wastes, through self-tortures of all kinds, through good foods, through love, through vigorous athletics. There have always been, so far as we know, natural drugs and alcoholic beverages, and today there are a great variety of these, of which LSD is probably the most spectacularly publicized. Each epoch has practiced its own rituals and utilized its available media. Now, you might say, we are proposing to employ machines for similar purposes.

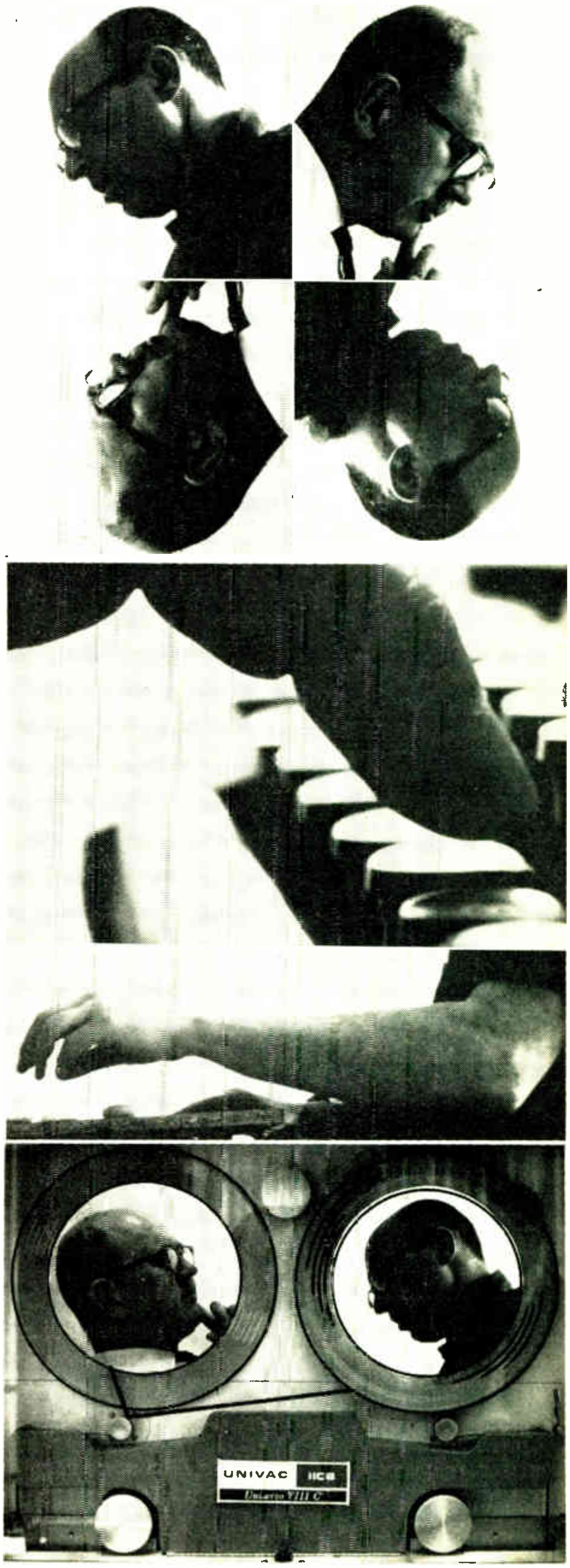
But the reader is misunderstanding us if he thinks this is all we mean. We are not urging merely a new kind of calisthenics, although it is not hard to imagine that intelligent evolutionary devices would be used for such purposes (especially when such devices become cheap enough and easily available). What we are urging is that engineers become aware of the new tools of artificial intelligence that are now falling into their hands. Machine intelligence—logic boxes, if you will—could give machines a capacity to interact with the human at a level of detail that isn't restricted to a simplistic game. We are urging them to set themselves up to explore the evolutionary capabilities of man and to investigate the various aspects of the phenomenon of dialogue. We are saying that the situation now vis-à-vis intelligent machines is analogous to the situation of man at the beginning of the industrial revolution. At that time, men must generally have held the concept (rapidly becoming obsolete) that work was for the muscles of men and for animals. But along came the engineers finding ways of distributing muscle work among machines. At first, the machines were expensive, and men had to be brought together in work pools, in factories, near the machines and their sources of power. Then engineers found ways of distributing energy more simply and economically, so that now wherever you have electric plugs, you have muscle power to run dishwashers, air conditioners, etc.

In this new epoch, which Wiener called the Second Industrial Revolution, we are beginning to see the evolution of distributed intelligence, and men may begin to discover ways in which certain tasks of intellect and control, which we have long considered innate to man and as part of his privileged domain, may be delegated more economically and more satisfactorily to his environment. But to do this, the engineer must throw over old habits of thought, which are certainly relevant to the purely physical environment, and he must discover how to conceptualize man. He must learn the laws for observing in the situation where observer and observed are of the same species and influenced by each other's acts even as they occur. These laws of operation are manifestly different from physical nature. The engineer, we believe, must go about discovering the evolutionary character of man through essentially evolutionary processes. He cannot start out measuring and specifying man with set physical parameters brought over by main force from the world of physics, from mainly cause-and-effect models. For this purpose, man must be measured as an evolutionary creature. The new tools of artificial intelligence make it possible to synthesize and model evolutionary processes in man, because these new tools can also be given evolutionary powers and can enter into dialogue. Nor are we talking here about some form of "average" evolutionary process. Plainly, some men are geniuses, with mighty capabilities of conceptualizing, and other men are dolts, who nonetheless yearn for satisfactions they should not be denied. And some men may *seem* like dolts, but may well harbor perceptual powers and views that they have been unable to express or formalize within the available means and that society has not learned to appreciate or tap for its benefit. Through new intelligent media and tools, such men might well "come to life." But we will never know for sure until we have tested and tried the limitations and the possibilities of the new media.

Evolving vs. the old conditioning

Thus, the new evolutionary tools, in their "nature," should be shaped with a "requisite flexibility and variety" to satisfy individual users. Certainly, in the beginning (*now!*), the efforts at bringing evolutionary powers to our machines, and the enhancement of human capabilities, must be modest, but the evolutionary process itself is bound to proliferate into steadily deepening possibilities.

Not least of all, we must consider the incalculable benefits that could be brought to the young, the next generation. In point of fact, we should remember that engineers today are largely designing the environment for the next generation. The new generation, the young kids, who are open and alive and curious and experimental, who are learning the new science, who are learning new concepts, won't, through the new evolutionary tools, be restricted by the relatively simple formal means of our generation (e.g., the workbooks with blanks that the child or man



must service). The simple linear and Aristotelian conceptualization that has governed the learning process up to the present has, on the whole, been more stultifying than enlivening. It shut out, rather than permitted, the metabolism of novelty on which the human spirit feeds. Nor did this older formal means allow the control finesse necessary to drive a student safely beyond his conditioned fears, to disorganize his conventions of what is humanly possible, to drive him just far enough into ambiguity, confusion, and absurdity where he could reorganize his mental patterns in accord with a deeper reality. Such evolutionary tools could make better scientists of the young, or better doctors, or better psychologists, or whatever. Young children are the world's "natural" scientists. Through new media of modeling and conceptualizing, their whole conceptual training could evolve faster and more richly, their curiosities and capabilities could be enhanced rather than quashed by the machinery of education. Education would be made relevant to them and their personal lives; it would be more than just something out of a book. Again, we won't know the possibilities in this direction until we have tried.

The devices of entertainment that could grow out of intelligent machines could be enormous. We won't even bother trying to specify what such devices might be like. Suffice it to say that any device can be treated as a toy; we are safe in assuming, we believe, that there will always be entrepreneur types who will find novel ways of exploiting such devices. Not that we have anything against toys; we ask only that they be lively enough to help us enjoy our own aliveness.

Using the lead time

The reader who has come this far with us must sense the open-ended, rather "soft," unfinished character of the ideas we have put forward. Perhaps, he might say, it is far too early to attempt to crystallize ideas that are still unfolding. But—and this is a matter of judgment—we believe that the accelerating effects of our technological pollution give us very little "lead time" in bringing these effects under human control. We do not think of evolutionary technology as utopian, but necessary; and we think the time for engineers to join in the necessary dialogue is now. The decisions about the deployment of government resources to answer the problems of technological pollution are being made now, and these decisions could have positive effects on the life we enjoy in the future, or they could lead to waste and irrelevancy in that life.

There will be those who will object that the computer construction art, and the science of artificial intelligence, is too little advanced to undertake the kinds of evolutionary tasks we have talked about. But we must be careful not to misjudge the breathtaking swiftness with which the computer art is exploding within our social organization. The scientists of artificial intelligence—Minsky, McCarthy, Simon, Newell, Samuel, Papert, and many others—are busy evolving their machines; the cost of on-line computational capacities is dropping at a remarkable rate; and time-shared computer systems, regarded as the necessary take-off stage for widespread on-line intelligence, have been pushed hard in the past few years by Licklider, Corbató, Fano, Shaw, Selfridge, and many others.

Our computers are still young, and despite all the bluster about their powers, are still more like insects than mammals—hard-shelled, quick, busy, rigidly constrained in their maneuvers, persistent and exacting in their repetitive tasks, and rapidly multiplying. If we manage them in the way we have managed our earlier machines, and give them anarchic powers within the human community, we too shall behave in a more insectlike way.

But our computers are growing in influence, as well as intelligence, so there should be support for evolving their "sensitivities" in using humanlike intelligence.

Properly managed, these new computational powers could bring a new beauty and true functionalism to engineering, could mediate between us and the harsh automating effects of our present technology, could bring new satisfactions to the human users of technology, and could perhaps stabilize the rapid change of our environment. Although the work has begun, it needs the momentum of the whole community of engineers. The lead time is short.

A subsequent article will discuss practical examples of evolutionary design that are now under way or being contemplated; it will aim at concretizing the questions that have been treated here in a philosophical vein.

A word about this coauthorship. The ideas and the philosophical outlook are Brodey's. In order to elucidate the evolutionary idea, we have engaged in the kind of dialogue described in the article. Original photos are by courtesy of George DeVincent.

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Spectral dependence of deep-space communications capability

The relative effectiveness of laser and radio-frequency techniques in deep-space communications links is considered. By the mid-1970s it is suggested that maximum information transfer in this environment may occur in the region of 10 GHz

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A simple model of communications capability projected for the mid-1970s is formulated. The spectral dependence of the future state of the art is examined in terms of antennas, noise, diffraction effects, etc. The model suggests that the frequency spectrum in the vicinity of 10^{10} Hz would allow maximum information transfer and that radio-frequency techniques may be superior to the laser.

Deep-space explorations would benefit from communications rates far in excess of those that characterize today's missions. Several recent studies[1-9] have examined the possibility of using laser systems to improve deep-space communications rates, or have re-examined the growth potential of the older, but still rapidly developing, radio-frequency technology. Although these studies deal with particular aspects of the deep-space communications problem, there is still a need for a more general review of some basic considerations that may determine the relative growth potential of communications systems operating at different frequencies.

This article will attempt to reach a meaningful estimate of communication capabilities in the mid-1970s on the basis of fundamental constraints on communication systems rather than on the basis of predictions of hardware limitations. However, we must rely in part on the estimated improvements in the state of the art for transmitting and receiving antennas. Fortunately, estimates of their development potential taken from several independent studies are in essential agreement, so these estimates can be made on reasonably firm ground.

The effectiveness of any future communications system will be influenced by many hardware-related factors other than those introduced by antenna characteristics. For example, highly efficient, reliable, lightweight transmitters, receivers, modulators, and detectors do not exist in some portions of the spectrum. Further, the cost effectiveness of systems based on these devices is not considered. Although hardware availability, performance, and cost will certainly have an important effect on any practical system, these factors are ignored throughout the analysis for two reasons: First, limitations in the state of the art tend to be eliminated by unpredictable "jumps" and, therefore, neither cost nor performance can be properly accounted for; second, if they prove to be the critical deterrent to effective communications in an otherwise attractive portion of the spectrum, it is assumed they will yield to research.

Analysis

To study the general form of the spectral dependence of communication capabilities, we will develop an equation describing the capability of a deep-space communication link and evaluate the improvement potential for each factor in the equation. For our purposes, the power signal-to-noise ratio may be defined as

$$\frac{S}{N} = \frac{P_r}{P_0 B} \tag{1}$$

where P_r is the signal power received, B is the bandwidth, and P_0 is taken to equal the additive noise power per cycle plus the quantum energy contained in the number of photons required to provide an average of one detected photon per cycle of bandwidth. Although these two components of P_0 have different functional relationships to the bit error rate, this difference will not be important to the final results. For bit error rates of 10^{-3} or 10^{-5}, the SNRs required to maintain a constant error rate for appropriate signaling codes do not vary by more than a factor of 2 over the frequency range of interest.

From simple geometric considerations, the relationship between P_r and the transmitted power P_t is

$$P_r = P_t \frac{A_r}{A_i} \tag{2}$$

where A_r and A_i are, respectively, the effective area of the receiver and the equivalent area (in the "plane" of the receiver) illuminated by the transmitter. If A_i is limited solely by diffraction, pointing error, thermal defocusing,

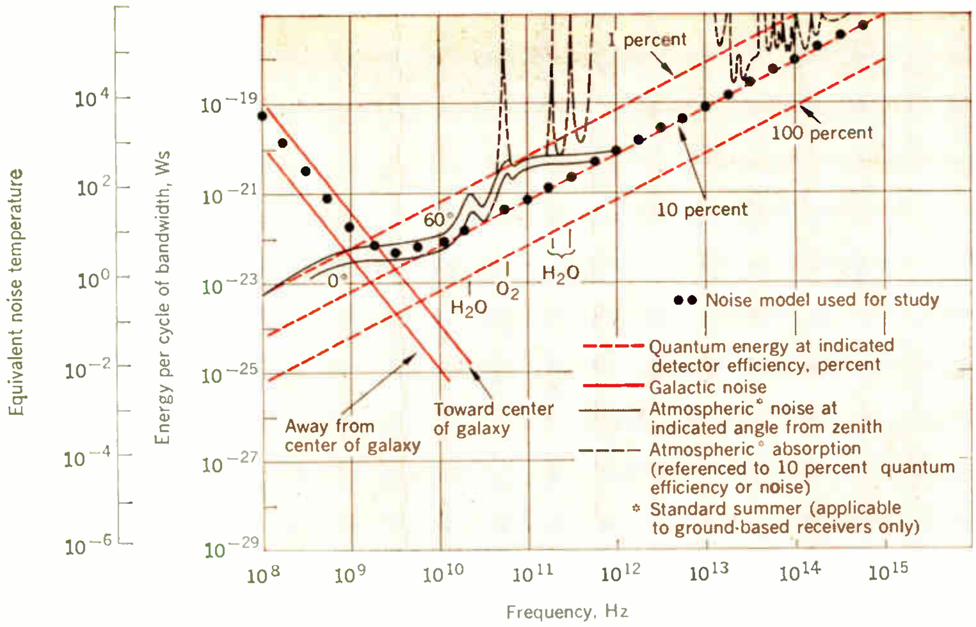

FIGURE 1. Spectral dependence of noise power and atmospheric absorption. Noise model: $P_0 = (10^{0.7}f^{-2.5} + 10^{-32.2}f)$.

or the need to cover a minimum area to be certain of including the receiver, the equations for A_t are

$$A_t = \pi(\alpha_d D)^2 = \frac{0.09\pi c^2 D^2}{f^2 R_t^2}$$

$$A_t = \pi(\alpha_p D)^2 \qquad A_t = \pi(\alpha_f D)^2 \qquad A = \pi R_m^2$$

where

c = velocity of propagation
D = range
f = frequency of transmission
α_d = half angle resulting from the Airy diffraction limit for the transmitting antenna $\equiv 0.3\lambda/R_t$
α_f = half angle resulting from imperfect focusing (owing to thermal expansions, etc.) of the transmitter
α_p = half angle due to the beam broadening required to avoid loss of signal because of imperfect pointing of the transmitter
R_t = effective radius of the transmitting antenna
R_m = minimum radius of the illuminated circle required to be certain of including the receiver

If the diffraction-limited area is factored from the resulting equation that describes the combined effects,

$$A_t \equiv \frac{0.09\pi c^2 D^2}{f^2 R_t^2} U \tag{3}$$

where U is the ratio of the actual A_t to the A_t that results from diffraction limits alone. Substituting (2) and (3) in (1), and the value πR_r^2 for A_r, yields

$$\frac{S}{N} = \frac{f^2 P_t R_r^2 R_t^2}{0.09c^2 P_0 B D^2 U} \tag{4}$$

Transposing and dividing both sides of (4) by D_s^2, the square of the distance between the earth and the sun, we obtain an expression for the communications capability

$$C \equiv \frac{S}{N}\frac{B}{P_t}\left(\frac{D}{D_s}\right)^2 = \frac{f^2}{0.09c^2}\frac{1}{P_0}\frac{R_t^2 R_r^2}{D_s^2}\frac{1}{U} \tag{5}$$

where C is the signal-to-noise power ratio normalized for range and for transmitter power required per cycle of bandwidth.

The problem of predicting the relative effectiveness of communication as a function of frequency now is divided into a series of smaller problems that establish the spectral dependence of the future state of the art on P_0^{-1}, R_r^2, R_t^2, and U^{-1}. We will consider these problems in their respective order and finally combine the results to estimate the total capability.

The power required to detect a signal is related to four separate factors: the quantum energy for the signal itself, the efficiency of the detector, the existence and strength of noise sources, and the existence and strength of any energy absorbers in the communication path. With a few exceptions, the pertinent information concerning these factors is presented in Fig. 1. Minimum signal energy requirements due to quantum energy are presented (a series of short dashed lines) for detectors with quantum efficiencies of 100, 10, and 1 percent.

Noise sources such as the earth's atmosphere and the galaxy tend to be characterized by a surface "brightness." For such a source, an antenna of increased area receives a larger fraction of the energy radiated from the section of the source viewed, but sees a correspondingly smaller fraction of the source. In effect, the noise power received is not dependent on the size of the receiving antenna; this conclusion assumes that the antenna is a single structure. Phased arrays can be arranged so that coherent reception of the array is limited to sources originating within an angle that is determined by the diffraction limit based on the diameter of the array, rather than its individual elements. Such an arrangement lowers the noise power (relative to a single antenna of equal total area) introduced by the earth's atmosphere or by galactic background by an amount to be determined for each specific receiving antenna configuration. Because this presentation does not include improvements derived from such arrays, it tends, in part, to discriminate unduly against the lower-frequency regime, where galactic and atmospheric noise limit the projected performance.

The curves for galactic noise (a pair of lines comprised of long dashes separated by single dots) in Fig. 1 show two levels. The higher level would be expected when the receiving antenna is directed toward the center of our galaxy; the lower level corresponds to pointing away from its center. The effects of discrete noise sources such as the sun, radio stars, and bright optical stars are omitted but would have to be considered as possible sources of interference during critical phases of some missions. The sun, in particular, would be a significant noise source for some missions and might introduce important multipath effects, Doppler shifts, and Faraday rotations. Intensity and phase variations caused by these effects would contribute to fading.[10]

The characteristics of the earth's atmosphere as a source of noise or as an energy absorber are highly dependent on weather conditions. Cloud cover, humidity, rainfall, and electrical storms can degrade the performance of a communications system 20 dB or more below that obtainable at a remote, dry, clear site.

In treating the question of atmospheric effects, we can take two extreme positions: (1) The communications system must perform at normal capacity under the worst weather conditions (for an antenna-zenith angle of 80° during a rainfall of 1.25 cm per hour,[3] for example). (2) Sufficient redundancy in receiver site location can be provided to maintain at least one site at nearly ideal conditions. In cases where limited data rates make the integrity of the transmission critical to the success of the mission, an assumption similar to the "worst condition" criterion is the only reasonable basis for design. It is clear, however, that not all the data in a wide-bandwidth communication channel will need to be treated so conservatively. As a compromise between the two extreme approaches, one can assume that the need for high-data-rate communication with deep-space probes will justify a limited redundancy of receiver sites, which will permit the "worst condition" criterion to be relaxed. On this basis one need consider only the likelihood of simultaneous degradation at successive receiver sites, certainly a constraint of lesser magnitude and one that occurs less frequently than that listed in the NASA reports.[3] The possible improvement suggested by the use of redundant receiving sites has led us to use a model atmosphere that involves a smaller performance penalty—the standard summer atmosphere viewed through antenna-zenith angles of 0° and 60°.

Effects of the earth's standard summer atmosphere are also illustrated in Fig. 1. Atmospheric noise is shown (solid black lines) for antenna-zenith angles of 0° and 60°; atmospheric absorption effects are indicated (black dashed lines) for an antenna-zenith angle of 0°. This absorption necessitates an increase in the intensity of the radiation incident on top of the earth's atmosphere so that after absorption adequate power for reception appears at the ground-based receiver site. The intensity of the received beam is subject to inherent statistical fluctuations owing to the nature of the absorption process. Partly in compensation for the requirements imposed by this process and partly in recognition of the state of the art for quantum detectors, the absorption effect of the earth's atmosphere is shown as energy in excess of that required for a receiver with 10 percent quantum efficiency. The effective quantum efficiency could be adjusted upward or downward if it were thought that the state of the art would be less or more developed.

The effects of both atmospheric noise and atmospheric absorption would be eliminated if the communications from the deep-space probe were received by an earth-orbiting satellite and relayed to the earth. Although this mode of operation has obvious advantages, the operational complications involved are certainly to be avoided unless the requirements of future missions cannot be met by receivers on the earth.

A useful first-order model for the noise power at the receiver is shown in Fig. 1 (large solid dots) and is described by the expression

$$P_0^{-1} = (10^{0.7}f^{-2.5} + 10^{-32.2}f)^{-1} \qquad (6)$$

Deviations from that model (introduced by atmospheric absorption, for example) will be added separately after the overall spectral dependence of C is determined on the basis of the first-order model.

The second frequency-dependent factor in the equation for communication capability is the size of the receiving antenna, R_r^2. The model for future receiving antennas is shown in Fig. 2 (solid line), and is given by

$$R_r^2 = 10^{11.07}f^{-0.73} \qquad (7)$$

This model is an interpolation between a point representing the radio-frequency antennas achievable in the mid-1970s as predicted by Patton and Glenn[2] and a point representing the achievable optical receiving telescope as predicted by Brinkman and Stokes[1] for the same period. These two sources were selected because their results seem to typify the projections of those who favor the RF and optical technologies, respectively. To check the validity of the model thus derived, the physical dimensions of various RF and optical "antennas" (solid dots) and the effective apertures for many of the same antennas (open dots) are plotted in Fig. 2. Note that a line drawn through the dots representing the effective apertures of existing antennas lies 1.2 orders of magnitude below and parallel to the model derived for the future. Since the present technology in both the RF and optical areas is the result of years of development, and it does not appear unreasonable to assume that similar efforts in the different frequency regimes would produce like advances, the fact that the lines representing the current and the possible future states of the art are parallel lends credibility to the predictions. Whether or not 1.2 orders of magnitude is a reasonable estimate for the operational improvement attainable in ten years is open to some debate.[4] It is clear, however, that as long as it is uniform across the spectrum, the magnitude of the estimated antenna improvements would not significantly alter the factor of greatest concern—the relative spectral dependence of future communications capability.

The model for future transmitting antennas is shown in Fig. 2 (dotted line) and is described by the equation

$$R_t^2 = 10^{6.37}f^{-0.48} \qquad (8)$$

For consistency, this model is again an interpolation between points supplied by Patton and Glenn and by Brinkman and Stokes. The radio-frequency portion of this model may seem optimistic in view of performance for Mariner II (1962)[5] and Mariner IV (1964).[11] The antennas used on these missions, however, were designed for

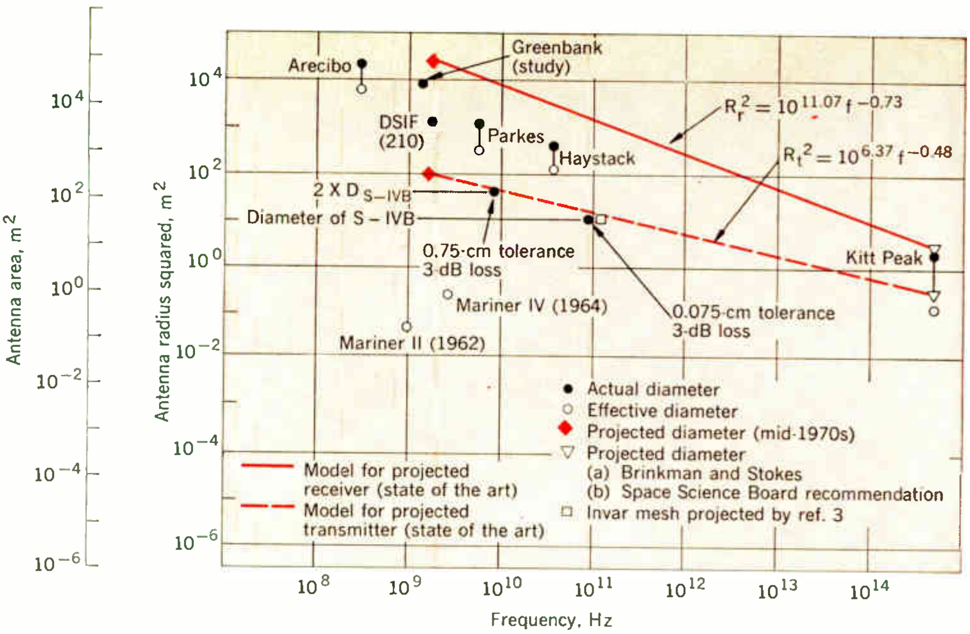

FIGURE 2. Antenna capabilities.

use on a spacecraft with stringent size and weight limitations. Boosters, such as Saturn, should allow considerable relaxation of these constraints. The limit in aperture diameter that would be imposed if the transmitting antenna were one piece with a diameter approximately equal to that of Saturn IVB is shown in Fig. 2 as a short solid line. The line is terminated at the high-frequency end by a point that represents the combination of a structural limit preventing better than a 0.075-cm surface tolerance,[3] and a performance limit allowing no more than a 3-dB performance loss. A similar line is drawn for the case of an articulated or erectable structure of effective diameter twice that of the Saturn IVB, where the structural tolerance has been increased to 0.75 cm. These points lie reasonably close to the transmitting antenna model.

Further support for the validity of the transmitting antenna model is provided by the results of several studies. The first of these[3] indicates that by the mid-1970s development programs could provide Invar-mesh antennas operating at 1.2×10^{11} Hz with an effective area of 30 m^2 and a total weight (including penalties for erection) of 340 kg. A second group of studies[9,12] relates to the optical end of the spectrum and indicates that the weight of a one-meter-diameter spacecraft telescope and its associated structure would again be of the order of 340 kg. In addition, weight penalties for the optical communication package include those resulting from the use of shrouds and pointing controls (necessary to avoid damage resulting from direct viewing of the sun), acquisition telescopes, fine pointing controls, either focusing controls or insulation shields (required to prevent excess thermal defocusing), and any equipment that might be required to refinish the telescope mirror surface after long exposure to the space environment. These penalties are not assessed because they are not as fundamental as those imposed by antenna size limitations and are more likely to yield to research and development efforts.

The model for future transmitting antennas is supported further by Brinkman and Stokes and by Patton and Glenn, who also estimate the same weights for both optical and RF antennas. The estimate of optical antenna capability is further supported by the Woods Hole Conference of the Space Science Board,[13] which recommended a NASA program that would lead to the availability of a prototype, earth-orbiting telescope 3.05 meters in diameter by the mid-1970s; and by the fact that the Orbiting Astronomical Observatory, currently in preparation, will orbit telescopes approximately 0.9 meter in diameter. The former objective allows for a telescope of considerably larger diameter than that projected by Brinkman and Stokes, but one intended for near-earth orbit and which would be available only as a prototype at the time of interest. The prototype should provide a telescope essentially identical to that projected by Brinkman and Stokes, but one intended for near-earth orbit on a vehicle totally devoted to the support of the telescope. The telescope used for transmitting from the spacecraft, by contrast, would be used on board a deep-space probe devoted primarily to a separate scientific objective. Considering these facts and the effects of modified constraints, one develops a measure of confidence in the estimated improvement in the optical state of the art as stated by Brinkman and Stokes.

The last factor in the communications capability equation that requires assessment is U^{-1}. We will consider first the interplay between the diffraction-limited beam angle and the possible requirement that some minimum area at the earth be illuminated to be certain of illuminating the receiving antenna. A spacecraft communication system that relies on an earth-based receiver or a relay satellite in near-earth orbit would necessarily be designed either to cover areas sufficiently large to include all sites potentially occupied by the receiver or, alternatively, would have to sense and track the apparent site of the receiver and correct the transmitter pointing apparatus for motion of the receiving site during the interval required for exchanging information between transmitter and receiver. This latter problem may be avoided, at the cost of increased system complexity, by using a pair of "receiving" satellites—a "beacon" satellite transmitting

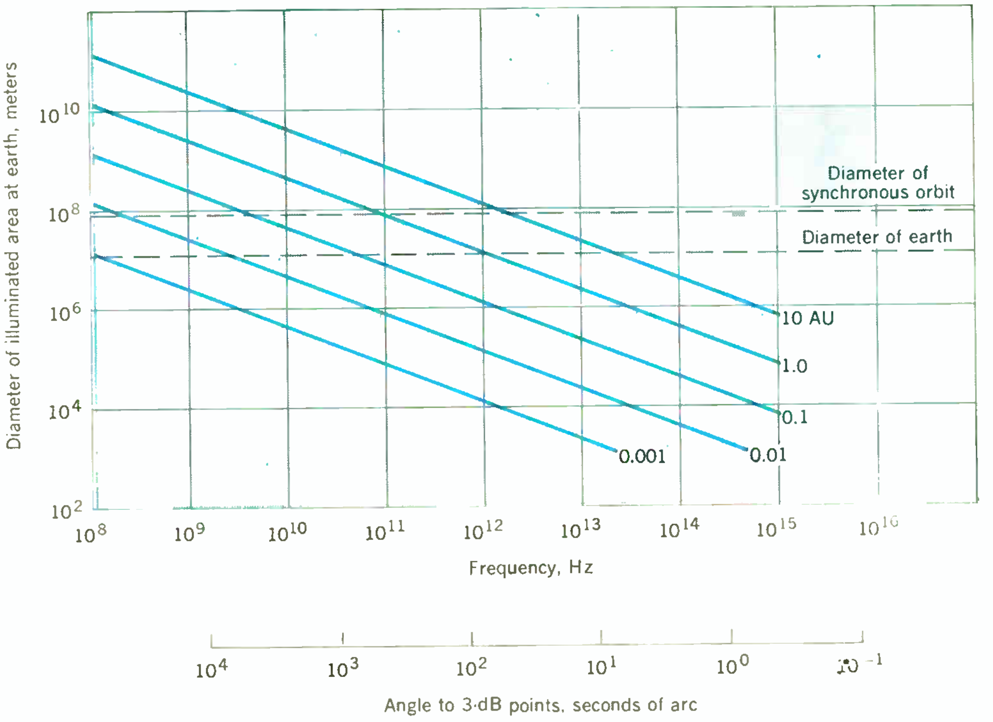

FIGURE 3. Diameter of disk illuminated by diffraction-limited spacecraft antennas; projected state of the art.

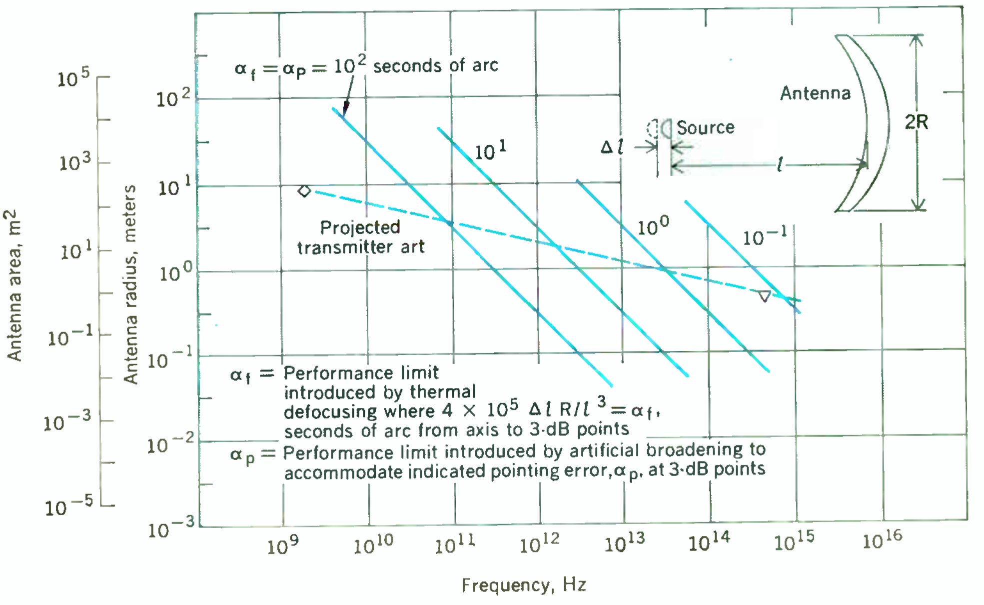

FIGURE 4. Pointing error and thermal expansion limits upon achievable aperture.

a beam of energy to a "beam rider" deep-space probe, and a receiver satellite adjusted by station keeping to be in position to receive energy directed from the deep-space probe toward the apparent position of the beacon. Whatever the method of overcoming the problem, the greater sophistication required in those cases where "lead" pointing is used will produce related penalties in weight and reliability. The conditions under which this problem is important are better understood by reference to Fig. 3, which shows the diameters of the earth and of the synchronous earth orbit (horizontal dashed lines). The lowest diagonal line represents the area that would be illuminated by the projected diffraction-limited antennas (varying in diameter with frequency) for a mission 0.001 *AU* from the earth, somewhat inside the lunar orbit. Because the area of the earth is always greater than diffraction-limited areas, artificial broadening of the antenna pattern would be necessary at any frequency if the lead-pointing problem is to be avoided. A similar line for a mission 1 *AU* from the earth shows, for example, that at this distance either artificial broadening to cover an earth-based receiver or dynamic tracking of the receiving site would become a problem only for communication at frequencies above 9×10^{11} Hz. Weight and reliability penalties inherent in system operation at this distance and at such higher frequencies require separate study.

The other component contributing to the value of U^{-1} is the combined effect of pointing error and trans-

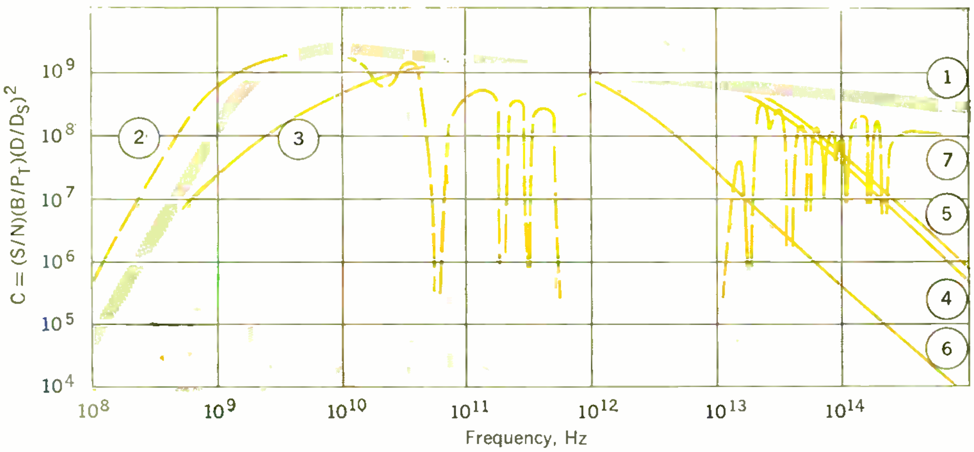

FIGURE 5. Variation of communication capability with frequency.

① Simple model for communication capability with modifications due to:
② Receiver pointing away from galactic center
③ Receiver antenna temperature limited to 40°K
④ Pointing and defocusing limit of 1 second of arc
⑤ Full earth coverage, 10 AU mission
⑥ Full earth coverage, 1 AU mission
⑦ Atmospheric noise and absorption

mitting antenna defocusing, introduced, for example, by uncorrected thermal expansions; these effects are shown graphically in Fig. 4. Again, the projected state of the art for the transmitting antennas of the mid-1970s is shown by the long dashed line. In the presence of pointing error it is assumed that the transmitter beam would be artificially broadened beyond the achievable diffraction limit to insure adequate coverage of the receiver site. On this basis, pointing errors due to effects such as imperfect angle control, inaccurate beam rider control, or lack of adequate compensation for the lead errors related to receiver motion introduce performance limits equivalent to those introduced by diffraction-limited antennas of sizes indicated by the series of solid lines labeled α_p, the value of pointing error. Defocusing due to thermal expansions, relief of structural stresses, or lack of adequate precision in any focusing control system produces similar effects (shown by the same solid lines). These lines are labeled α_f, the effective fractional displacement of the transmitter position relative to its ideal position divided by the ratio of the focal length to the diameter of the transmitting antenna.

To obtain an approximation of the overall limit in transmitting antenna gain as a function of frequency, one proceeds toward higher frequencies along the line describing the state of the art for the transmitting antenna until this line intercepts the first of the lines describing the limit of attainable pointing accuracy or defocusing limits, then along that particular curve toward the optical end of the spectrum.

In developing the first approximation for the spectral dependence of the future communications capability, the only factors that will be included are noise power and the projected state of the antenna art. The projected communications capability is obtained by combining (5), (6), (7), and (8) to yield

$$C = \frac{10^{-21.5}}{U(f^{-3.3} + 10^{-32.9}f^{0.2})} \qquad (9)$$

With the assumption that $U = 1$, (9) is shown graphically as curve 1 in Fig. 5. A series of modifications of the simple model is also included in this figure. Curve 2 shows the improvement in performance expected if the mission of concern is scheduled so that receiving antennas can be pointed away from galactic center during the critical phases of the deep-space mission. Curve 3 indicates the effect of penalties to be assessed if effective receiving antenna temperatures in the future cannot be improved significantly beyond 40°K. Curve 4 indicates the additional performance penalty that results if overall pointing accuracy or "thermal" defocusing effects limited the effective beam width to one second of arc. Curves 5 and 6 point out the penalty resulting if full earth illumination were required and the maximum ranges of communications were 10 and 1 *AU* respectively. The dashed line identified as curve 7 indicates the penalty imposed when signals are received at earth-based installations after attenuation by the standard summer atmosphere[14] and the addition of atmospheric noise for an antenna-zenith angle of 60°.

An indication of the insensitivity of the conclusions to small changes in the antenna models is obtained by considering a communication link operating at a frequency of 10^{10} Hz with the receiving antenna limited to a 64-meter instead of the projected 152-meter diameter. Although this reduces performance by a factor of 6, the conclusions of the study are not significantly changed.

The effect of combining the various effects described can be obtained graphically by adding the displacements from the reference model due to the separate effects of interest. A particular combination of these effects has been plotted in Fig. 6. The model shown by the solid line is based on a 15°K earth-based receiver pointing toward galactic center and receiving signals from Mars at conjunction. Included for reference is a dashed line based on an earth-orbiting receiver for the same conditions.

The mission "requirements" for a Mars probe[12] are also shown in Fig. 6 (broad shaded line). These requirements are based on a signal-to-noise ratio of 10, a transmitted power of 10 watts, and the ability to provide effective communications to the earth over a bandwidth

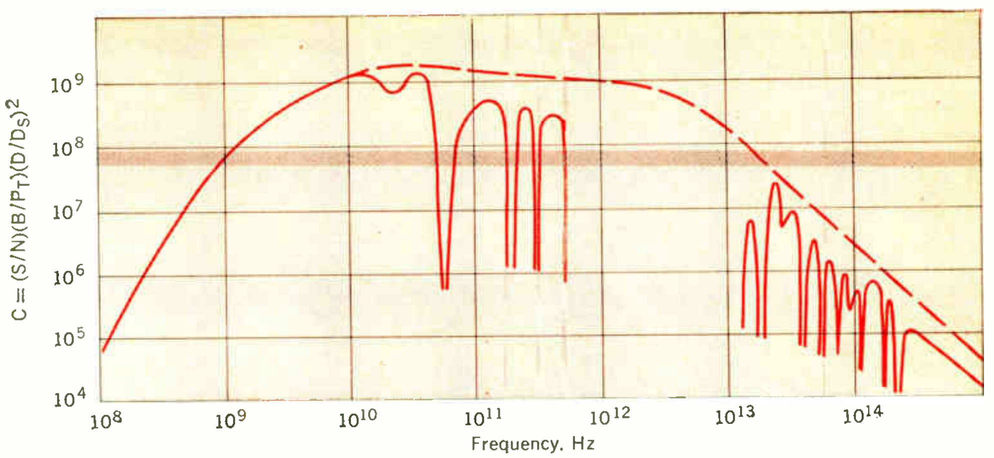

FIGURE 6. Estimated state-of-the-art limit on communication capability; mid-1970s, Mars mission, full earth illumination.

of 10^7 Hz when the spacecraft is near Mars and Mars is near conjunction; effects of the sun are not included.

Discussion

The simple model of communications capabilities projected for the mid-1970s includes the effects of minimum power required to recognize a signal in the presence of noise and the effect of the estimated state of the art in antenna design. The model suggests that the frequency regime that would allow maximum information transfer is in the portion of the spectrum centered around 10^{10} Hz. Even if one assumes reception by a satellite above the earth's atmosphere and no limitations in performance imposed by any hardware other than antennas, communication at frequencies near the optical end of the spectrum seems to provide one order of magnitude poorer performance.

Reception of optical transmissions by earth-based receivers would degrade performance by an additional order of magnitude. Further degradation in the performance of deep-space optical communications links of several orders of magnitude may be caused by problems of pointing, tracking, thermal defocusing, etc.

This analysis indicates that efforts to develop increased deep-space communications capabilities should be directed to the development of operational systems in the band around 10^{10} Hz. Since the technology developed by the Jet Propulsion Laboratory in support of the Deep-Space Instrumentation Facility should be readily translatable to provide the projected capabilities, it should not be difficult to provide adequate bandwidth for a liberally interpreted Mars mission "requirement."

The conclusions from this study do not apply rigidly and generally to all deep-space communications problems. It is clearly impossible to imagine all the special communications problems that might be encountered that do not satisfy the premises stated or implied in this discussion. Questions of cost have not been considered and might have significant influence on the selection of optimum frequencies, even when competitive frequencies are located within a relatively narrow spectral region. One conclusion does emerge, however. The first enthusiastic suggestions that laser technology potentially provides many orders of magnitude more communication capability than RF technology, and that it might, therefore, offer the only solution to the problem of general wideband communications with deep-space probes, need to be more carefully assessed.

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Wanted: a physically possible theory of physics

A unified theory is needed to define the physical realities and limitations of the computational process. The physical scientist states that the tools of mathematics are physical; therefore mathematics is limited by nature

Rolf Landauer *International Business Machines Corporation*

The ability to predict the nature of physics in great detail depends upon the ultimate capabilities of information processing systems. Computing must be carried out in real systems, subject to physical laws. Thus an intertwining between the ultimate versions of the laws of physics and the computer is created. In order to satisfy this "want ad" for a unified theory, two conditions must be met: The type of information processing required in the study of physics must be recognized; and the physical laws governing information processing must be defined.

Science is expressed in mathematical terms; and to apply the laws of science, we have to rely on the operations of mathematics. In the normal course of scientific work it is assumed that we know what such operations as differentiation, calculation of a sine, or the solution of a partial differential equation involve, and that we can freely invoke such operations in the correct formulation of a scientific theory. Indeed it is generally assumed that with a good enough theory, and with enough paper, pencil, and perhaps the use of enough graduate student helpers, we can predict as much as we want about the events in the universe around us.

Although the process of calculation is thus taken for granted and is presumed to involve only economic barriers, the physicist has, during this century, evolved a very different attitude toward the measurement process. We have learned from relativity theory and quantum mechanics that the process of observation and the universe being observed are not two really separate things. Quantum mechanics in particular taught us that both the observing apparatus and the particle being watched were a part of the same world, governed by only one set of laws apparent to the struggling observer. The experimentalist could not, by diligence, perseverance, and the use of very small hands, go arbitrarily far in the determination of all the variables that he knew to be useful in describing the behavior of a particle. Thus modern physics, in its very formulation, acknowledges the limitations of the measurement process.

On this note we want to point out that the calculative process, just like the measurement process, is subject to some limitations. A sensible theory of physics must respect these limitations, and should not invoke calculative routines that in fact cannot be carried out. This basic philosophy is not really the author's invention; it was given earlier by P. W. Bridgman in a somewhat different form. Bridgman, in a number of careful discussions about physically meaningful operations, realized that the physicist's totality of relevant operations involves not only the manipulation of laboratory equipment but also "paper and pencil operations."[1-3] His "paper and pencil operations" are, of course, the calculative processes of physics.

Why do we believe that calculative processes are subject to limitations? Basically because we do not have available an inexhaustible supply of paper, pencils, and assistants. And if, in fact, we do maintain a very huge stock, it will have a physical effect on its own environment, through gravitational forces or through the heat generated in the writing process. In that case, we cannot ignore these effects upon the very accurate physical calculations that required the huge stock in the first place.

Today, of course, as a result of the evolution of data-processing machinery, we are aware that information can be handled in more subtle ways than by paper and pencil. But it is the very existence of these subtler processes that has caused us to think more carefully, and consequently to realize more clearly that information processing is subject to physical limitations. The machines for processing this information take up a real portion of the energy and the degrees of freedom available in this universe, and proceed with their tasks at finite speed. Furthermore, these machines have internal noise sources, which cannot be completely eliminated; therefore, though very accurate, they can never be perfectly reliable.

To illustrate the fallibility of the calculational process, consider the evaluation of π on paper, through the use of pencil. The mathematician has given us an idealized universe in which π, for example, is defined and clearly distinguished from all other numbers because we have rules for calculating π to an arbitrary number of places. Now we come back with such questions as, "Do we really know what π is, if the initial digits of π deteriorate away by atomic diffusion processes, after a finite number of years, and at a fairly well defined stage of the calculation?" or "Can we really distinguish π from a very close numerical neighbor if we compare the numbers, digit by digit, by methods that are very reliable but can never be made completely foolproof?"

The new kind of theory

Just as quantum mechanics allowed for the realities of the observational process, we are now suggesting that there is a physical theory that allows for the physical realities of the computational process. Quantum mechanics is not related to the shortcomings of actually available physical equipment; similarly, we do not expect an esthetic physical theory to be a function of the power of the human mind or of the capacity of currently available computers. We instead expect the theory to be compatible with the ultimate, and perfectly optimized computer.

Would such a new theory really be different from existing theories? Clearly, if we are describing the behavior of just a few particles, with only fair precision, over a stretch of time in which limited activity takes place, then one should be able to find a corner of the universe, and a time, sufficiently decoupled from these particles, and quietly do our computing there. At the other extreme, if we are doing cosmology, and describing the universe by a few statistical generalizations, again that should cause no great strain. Thus, in the typical situation we have known in the past, where there is relatively limited information handling, these informational aspects are unimportant and unlikely to influence the events under calculation. That, however, is typical of all refinements of physical theory: The new region of relevance always requires further excursions from the typically familiar human scale of size, energy, velocity, etc., up to the point of origin of the new theory. In the present case, we are talking about going beyond the readily available human scale in the *detail* of descriptions, and calculating the simultaneous behavior of very many particles, or the behavior of one particle, to an extreme degree of accuracy.

Let us discuss the timing of the calculation in more detail. If we are doing a very detailed calculation, consider first the possibility that we are doing the calculation entirely as an exercise in the hope of someday finding the particular set of detailed initial conditions reflected in that calculation. It seems unlikely that, in a really huge precision calculation, one would be taking such a chance on what the future may turn up. As a second and more likely case, consider that we may be doing a real-time calculation, attempting to race ahead from the given precise initial conditions, to predict (or even control) their outcome. Thus we might, for example, get involved in the question: "What is the earliest astronomic catastrophe that might put an end to mankind?" A third possible alternative involves a calculation done too late in time to affect the earlier history. Again this is a less likely case. Its only purpose would be to check our understanding of the laws involved, and one suspects this can be done without seeking out such a terribly complicated situation. But the timing of the calculation, in relation to the events, is likely to be part of the structure of the ultimate laws.

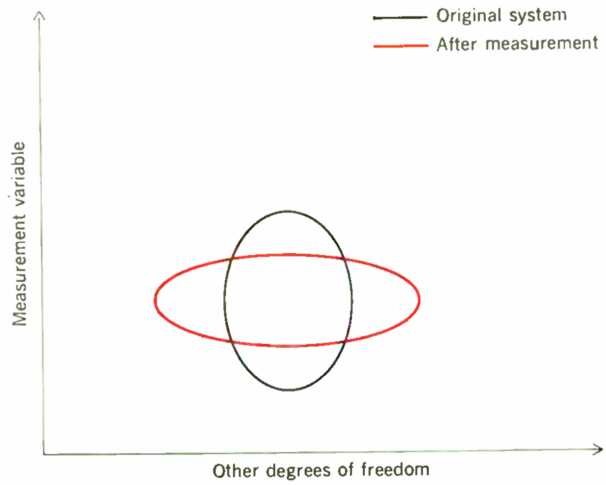

FIGURE 1. The original closed system is distorted due to a reduction in entropy, by measuring, and thereby limiting, the system. Since the system is closed, there must be a corresponding increase in entropy elsewhere, along remaining degrees of freedom, in order to comply with the laws of thermodynamics.

The birth of a theory as requested must rest upon two foundations. The first is a recognition of the sort of information processing required in studying nature; all of us have had the kind of mathematical training that gives us a feel for that. The other foundation, which concerns the physical laws governing information processing, is less well known. Indeed, answers to that exist today only in the most rudimentary fashion, and it is most likely that this theory requires much further development before the main plea of our present discussion can really be satisfied. On the other hand, it can be argued that quantum theory did not really emerge out of a detailed study of experimental apparatus, nor did relativity theory come out of a concern with the real practical difficulties of moving platforms. In that same sense the unified theory described in this "want ad" could, perhaps, be synthesized more easily. Actually we are, in first order, simply stating that the tools of mathematics are physical, and therefore that mathematics is limited by nature.

Physical description of computers

In connection with the desire for a description of the ultimate possible computer, let us present a brief picture of where we are in understanding the physics of information processing. A good deal has been written in recent years, as a result of the existence of lasers, about the signal-carrying capacity of information channels that carry quantized electromagnetic energy. This work is relevant to our present question, but it is not central to it. These communication channels are always linear, whereas all the crucial steps in data processing are nonlinear. Data processing involves streams of information flowing together

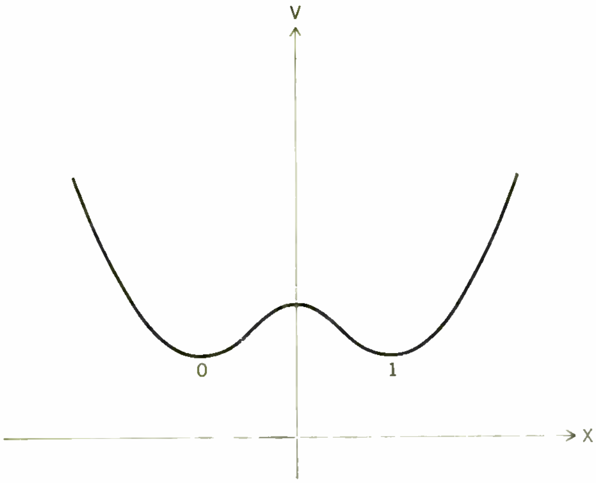

FIGURE 2. In this bistable potential well X is a generalized coordinate representing the quantity that is switched.

and thereby affecting each other—a distinctly nonlinear process.

A real first start toward the physics of information processing was made in 1929 by L. Szilard,[4] who realized that information about a system ties down its possible ways of behavior. Thus, when we have measured a system we have reduced its entropy, since entropy is characteristic of the extent to which a system is diversified in its behavior. Therefore, in a closed system, which includes both the item being measured and the measuring apparatus, there must be an increase of entropy elsewhere that more than compensates for the loss on the measured system; otherwise the second law of thermodynamics is violated. Figure 1 is an idealized representation of this concept, showing the system originally as being in the space denoted by a solid line, indicating a spread in both the coordinate to be measured as well as in the many other degrees of freedom of the system. If the measurement confines the vertical spread of the total system, as indicated by the dotted curve, then this must be made up through a spread of the system in the many remaining degrees of freedom. Brillouin has discussed this problem in detail.[5]

The next step in the development of the theory is trivial, if one understands the sign of information changes, during the computing process. A first naive reaction might be that information must be increased during information processing. After all, why else should one pay money for data processing? But that's incorrect. Information processing inevitably has to lose information. If we don't lose information, we can always go back from the output and deduce the input, a characteristic of "table lookup" procedures. In a table of logarithms we can go from a number to its logarithm, or vice versa. But then we are not really figuring out anything not already known to the original compiler of the table. A little more precisely: If we do not lose information, we are handling numbers, in a calculation which has been rigidly foreseen, step by step. In a general-purpose computational process, we must be able to do more than that; we must have the ability to make decisions during the computation. This in turn consists of the ability to take intermediate computational results and from them, rather than from all the intricate history leading up to these signals, proceed further. If we do not throw away information about the history, a given logical signal will depend on the exact way it was reached; then, after a sufficient number of steps, the accumulation of these historical characteristics would lead to errors. As is well known in computer technology, however, signals must continually be brought to standard forms of "0" and "1." This standardization process represents the elimination of the earlier unnecessary history. It enables us to proceed along almost arbitrarily long chains of digital process steps—in contrast, for example, to an analog computer. Thus we must be able to lose information, since we do not want the mechanism clogged up with irrelevant data. This argument can be given in more detail,[6] but it would be misrepresenting the case to say it's been "proved."

Information destruction

How is this information destruction accomplished physically? Information in computing machines is carried as binary data in systems that are put into either a "0" or a "1" state. Such a system can be typically idealized as a particle in a bistable potential trough, as shown in Fig. 2. The particle can sit in one of the two equally favored well positions. To destroy information, we can carry out an operation such as "Restore to one," which leaves the particle in the "one" state, regardless of its initial location. Can we do this without spending energy? If we are told that the particle is in the "one" state, then it is easy to leave it in that state, without spending energy. If on the other hand we are told that the particle is in the "zero" state, we can apply a force to it that will push it over the barrier. Then, when it has passed the maximum, we can apply a retarding force, so that when the particle arrives at "one" it will have no excess kinetic energy. We will not have expended any energy in the whole process, since we extracted energy from the particle in its downhill motion. One example of such a force, as a function of time, is shown in Fig. 3. Thus at first sight it seems possible to "restore to one" without any expenditure of energy. Note, however, that in order to avoid energy expenditure we have used two different routines, depending on the initial state of the device, whether "0" or "1." This is not how a computer operates. A computer must be able to push information around in a manner that is independent of the exact numbers which are being handled.

Once, however, we admit some energy losses into the system, it becomes easy to destroy information. Then we simply apply a force that favors the right-hand well, as shown in Fig. 4. If the system has a viscosity, or energy-loss mechanism, then the particle is also subject to thermal agitation, or "noise" disturbances. The correlation between loss behavior and thermal noise, which we are here invoking, is closely related to the Nyquist–Johnson relationship giving the thermal noise in a circuit as a function of the resistances in it. It is also related to the Einstein relationship, familiar in semiconductor and transistor lore, that relates the random diffusive behavior of an electron to its mobility under an applied electric field. In the presence of such thermal agitation the particle in Fig. 4 has a high probability of ending up in the favored well, even if we do not tip the trough enough to pour the particle right out of the unfavored left-hand well. Furthermore, in view of the viscosity, the particle will end up in the bottom of the favored well, without any excess kinetic

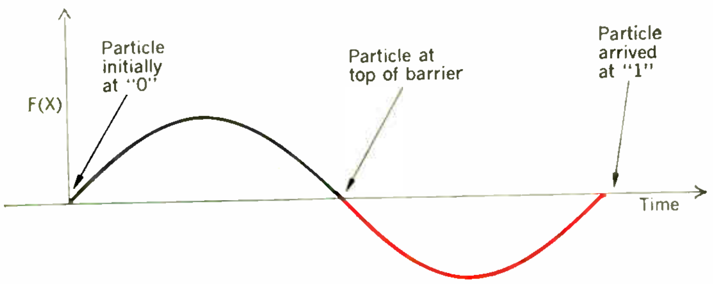

FIGURE 3. The particle is moved slowly from the "0" to the "1" position. The move is accomplished by an external force $F(X) = \partial V/\partial X$, which just balances the well force.

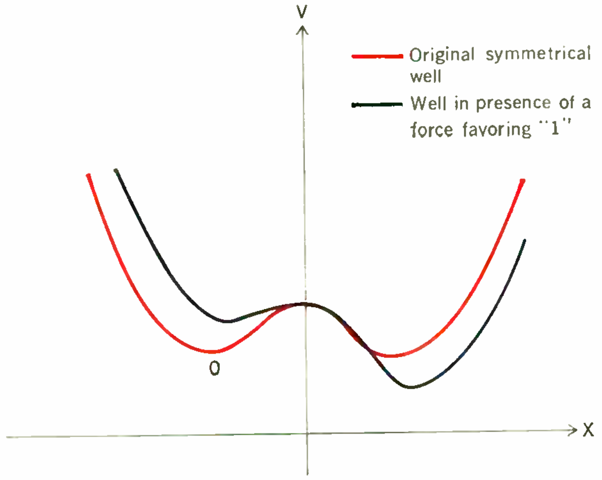

FIGURE 4. A biasing force is applied that favors the right-hand well, creating a high probability that the affected particle will come to rest there.

energy and therefore without any historical reminders of which well it had initially occupied. In order to ensure that the particle ends up in the right-hand well, the lowering of the favored well must be appreciably larger than the typical random thermal energy that the particle processes. This means that the energy lowering, and therefore the energy dissipated, must be several times kT. Here T is the absolute temperature in degrees Kelvin, and k is Boltzmann's constant, 1.37×10^{-23} joule per degree K.

We have thus seen that with energy expenditure it is possible to lose information in the fashion needed for satisfactory computer operation. It might be argued at this point that "a few kT" is not really a fixed quantity, since the temperature of the computer is at least somewhat under our control. For instance, we could do our computation at liquid-helium temperatures, instead of at room temperature. But additional consideration shows that in fact one gains nothing by using a refrigerator. It is true that kT within the computer is reduced, but the extra energy dissipated in the refrigerator more than makes up for that. Perhaps instead of using a refrigerator one simply parks the computer in a cold part of the world. The counterargument to that: It is unlikely that there are arbitrarily cold parts of the world. There is another problem with trying to run an extremely cold computer: The relaxation processes, which let the system settle into the designated well, typically tend to become very sluggish, and we cannot count on very fast switching.

Although a minimal necessary energy loss has been discussed, it is clear that the larger losses in practical systems can and do serve the same purpose. In fact, even in our idealized model of Fig. 1, faster switching can be obtained if desired by biasing the wells to a greater extent. It is readily shown[6] that in this model the switching time τ varies as $\tau_0/\cosh(U/2kT)$, where U is the energy loss in the process and τ_0 is the time in which an element, not intentionally subject to switching, will lose its information. This corresponds to the well-known practical computer lore that increased switching speed, for a given device, comes at the expense of increased power. If we require, as we do in practice, that the probability of an undesired spontaneous information change be very minute, compared to a desired one, then it becomes clear that τ must be very short compared to τ_0, and therefore U large compared to kT.

We have emphasized energy losses, of the order of kT, per switching event. For a single electron of charge e, jumping between two wells, this energy corresponds to a potential difference between wells of about kT/e. Now it is true that semiconductor junction devices have nonlinearities that are excited by voltages of just that order,[7] and therefore such minimum voltages are required in actual transistor switching circuits. But we believe this is a coincidence, and that a voltage limit of kT/e is not very basic, compared to the energy limit kT. If a number of electronic charges are tied together in their motion by some sort of cooperative action, then an energy loss of kT can correspond to a voltage smaller than kT/e. A detailed and fundamental analysis of active circuit behavior[8] suggests, in fact, that the circuit provides just this sort of cooperative coupling between charges.

We have argued that information loss is necessary and that it is, in turn, accompanied by energy loss. Not every circuit or memory element in a computer must lose information; but in practical computers we deal with a minimal diversity of elements. Therefore, as a practical result, all computer elements must be capable of energy dissipation. One is tempted to ask whether it is possible to build a computer out of a crystal in which every cell does useful information processing, the processing mechanism being provided by some natural physical interaction between adjacent cells. We cannot expect to have such an efficient utilization of the possible degrees of freedom, because there is not enough material left to act as heat reservoir and absorb the dissipated energy. Not only will the whole crystal quickly overheat, but the heat to be dissipated by each element is too likely to turn up as a disruptive influence on the next element, propagated through the intentional coupling that accomplishes the information processing, instead of being passed on to the innocuous other degrees of freedom constituting the heat reservoir.

Preservation of results in the presence of noise

Up to this point we have concentrated on information and energy losses. Although there is some information that has to be lost, there is naturally also a good deal of information, both data and programming, that must be retained in an unchanged form and protected against noise signals. It has already been pointed out that the very losses needed for processing are also a source of noise. We have referred to the Nyquist–Johnson relationship and the Einstein relationship to make this plausible. Just as small particles are more obviously subject to thermal agitation, resulting in Brownian motion, small information-bearing devices are more likely to lose their information than are large hefty ones. These Brownian-motion effects in information-bearing systems have been analyzed,[8,9] and very microscopic systems, far smaller than anything contemplated in modern microelectronics, are stable enough in principle. Nevertheless, the more complex the calculation becomes, the more severe the requirements on stability become, and therefore larger minimum sizes become necessary.

In principle, the position of a single particle, say an interstitial impurity in a crystal lattice, carries information and can hold information for long periods of time. But we cannot use this information; we have no way of reaching in to "read" it or to modify it. Typically, information handling has led to the use of systems in which a larger number of particles are tied together in their behavior, either through cooperative phenomena, such as ferromagnetism, ferroelectricity, and superconductivity, or else through the very similar action of an active electric circuit. Then, if the energy per participating particle involved in moving the particles from the "1" state to the "0" state is small compared to chemical binding energies, we have something that can be switched back and forth without disrupting the physical structure of the device. At the same time the "heat reservoir" required for the switching dissipation discussed in the preceding section is provided. One information-bearing degree of freedom is associated with many particles, and their irrelevant degrees of freedom act as the heat reservoir.

Not only is the information itself subject to undesired noise-induced deterioration, but during sufficiently long and complex calculation we can expect even the physical computer structure to deteriorate.

Another concept comes readily to mind: Isn't it possible to use a single particle to represent very much more than a binary choice and can't we permit the particle to take on an infinity of positions along a line? The moment, however, we allow for the random diffusive behavior of the particle, and for the uncertainty principle, we emerge with a particle whose allowed information-bearing positions must be separated by adequate error zones. In a machine of finite spatial extent (and all machines in which we can guarantee to ascertain the position of a particle in a finite time must have a finite size) only a limited number of states are allowed. In fact, it has been shown[6] that in the simplest models the presence of a barrier between particle states greatly increases the ratio of the time over which information can be preserved to the time needed for intentional switching. This ratio is a good measure of the usefulness of a device.

Further physical limitations on computers, which have so far defined a very fundamental analytical approach, come from the fact that a computer is not just a periodic array of devices, each of them interacting only with its nearest neighbors. A computer is a complex network in which devices some distance apart must sometimes interact with each other. Energy must therefore go some distance, without too much of it getting lost. Enough energy must arrive at the desired devices, and not too much at the wrong devices. In real computers with macroscopic electric transmission lines, this results in rather well-known engineering problems. The impact of this requirement on the ultimate possible scale of the computing process is not at all understood, except that the need for interconnections is one more reason why we cannot expect to utilize too many of the available degrees of freedom for information-holding elements.

Conclusion

Enough has been said to indicate that information processing proceeds in a real physical environment; and, for satisfactory operation, this situation imposes requirements upon both the physical structures and the energy consumption.

To return to our original epistemological concern: It should not be assumed that only the problem of following the time evolution of a substantial portion of the universe will generate a need for a new theory. Following the motion of a single particle can also be done, analytically, with only limited precision. We usually assume that solving differential equations (or any mapping process taking an event description and on the basis of it predicting the probability of other events contingent on it) can be carried out within any required accuracy. In reality, however, as the allowed computational error becomes smaller, more and more computational steps are required. Perhaps it is possible to trade time for computer complexity, and thus really avoid using substantial portions of the universe for the computer, which has to follow one particle very accurately; but it is far from clear that such trade-offs can be pushed arbitrarily far. Certainly they cannot in the case of real-time prediction. Moreover, longer calculations will certainly impose greater stability requirements on the computer and its information content.

Our plea contains some irony. The mathematicians' limiting processes arose from attempts to describe the physical universe: Newton's "fluxions" and the attempt to describe the real number system as an obvious idealization of a yardstick. Thermal agitation and the uncertainty principle have made us aware that these mathematical idealizations are not really crisp models of nature. We are now proceeding further and asserting that the mathematical processes themselves are not really capable of being carried out, and that we should not (even in pure mathematics) invoke processes that nature will not permit.

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IEEE publications

scanning the issues
advance abstracts
translated journals
special publications

Scanning the issues

Computer Teaching. In his introduction to a special issue on the subject, Gustave J. Rath affirms that everyone seems to agree that computer teaching is coming, but the question he raises is, "Where is it going?" In his review of computer-assisted instruction (CAI) over the period 1958–1961, the same Rath concludes that the question of whether CAI will be an expensive toy or a central contribution to education will be seen in the coming years. However it evolves, computer teaching is certain to create ferment, change, and interest. As practitioners of engineering, as builders and users of computers, as parents of students, it is to many of our concerns that information about this field will appeal.

Where and how will computer teaching find its most appropriate place? Rath says that it might become a technique to train special classes of students where a high cost is balanced against a higher social benefit. Or it might benefit special classes of students—the disadvantaged, the handicapped, and the very bright, as for example, medical students, for whom a high educational investment exists. Astronauts or high-positioned officials of industry and government, whose jobs or opportunities are special and where the cost of mistakes is quite high, might also benefit from the best available instruction (assuming that computer teaching could be the best).

Another purpose of computer-assisted instruction might be to test materials, techniques, and theories of education. Computerized-assisted instruction allows the investigator to vary, measure, and control educational variables in an effective fashion.

This special issue on computer teaching covers some of the new technological developments, novel trends, and current contributions of CAI. Rath notes that an effort has been made to go beyond CAI alone. The issue covers: (1) some early history of computer-assisted instruction; (2) a description of a major programmed computer system that teaches many students; (3) the concept of training computer users on computers; (4) the use of computers in complex educational games; (5) new software possibilities that would transform texts into computer-teaching materials; (6) the use of special-purpose devices for teaching new software applications; and (7) the teaching and training of computer-assisted instructional personnel. Rath says that it is significant that all of the papers deal with experimental systems that are not routinely available for use in schools and colleges. The well-known PLATO system, developed at the University of Illinois over the past six years, is the closest to a real-time operational training system.

At this point, the PLATO system is unique, however, and much of the work done with it is still experimental. Three successive models of the system have been evolved. Although initially conceived as an automatic teaching system, the PLATO system has found application in many areas of research and behavioral sciences. For instance, a real-time, on-line experiment in surface physics was studied using PLATO for control of data collection and analysis. Also, heart-rate correlates of insight were studied using the system for stimulus presentation and response.

Rath says that several needs are still apparent in the field of computer teaching. One is the need for serious, thoughtful, and scholarly studies of methods and techniques of computer instructional systems. This means: a better analysis of the techniques of using computers in educational environments with appropriate cost-effectiveness analysis; a finer description and evaluation of early production trials of computer-assisted systems; specific evaluations of the experiences of having teachers and administrators carrying out, administering, and running computer instructional systems; and further development of useful performance measures. The inception of large on-line time-sharing multiprocessed educational data-processing systems in universities, Rath argues, makes the response to these needs urgent. (*IEEE Trans. on Human Factors in Electronics*, June 1967.)

Radio-Frequency Measurements. Because of the demanding requirements of military and space applications, many important improvements have been made recently in the science and art of RF measurements, and because of their currency, many of these improvements are not yet covered by today's textbooks. Now, however, they are available for the first time in one volume, the first special issue of the PROCEEDINGS OF THE IEEE to be devoted exclusively to the extensive subject of radio-frequency measurements. Although many readers may not have an immediate reason for becoming acquainted in depth with the science and art of radio metrology, which this issue attempts ambitiously to cover definitively, they may at least wish to read the introduction by guest editors R. W. Beatty and B. O. Weinschel, which "places" the papers in the issue, interprets the trends in RF measurement, and tries to stir up interest in the kinds of challenges facing radio metrologists. Even if these papers do not "kindle the interest of young engineers and physicists in this basic, all-important, wide-open field of scientific investigation," the collection of techniques discussed will bring the interested engineer and scientist up to date and give him a convenient reference on the state of the art of accurate RF measurements.

In all, the issue has ten editorial and general articles describing activities of professional, semigovernmental, and governmental bodies that further research and establish standards, and 31 papers on specific technical subjects grouped under four categories: frequency and time; electromagnetic quantities; measurements from millimeter through optical wavelengths; and applications of RF measurement techniques. It is pointless to try to detail the subjects of these papers here. Just a few of the general observations of Beatty and Weinschel should be much more useful.

For instance, an engineer ought to be familiar with the accuracies of RF measurement presently available vis-à-vis operations or facilities he may be planning. Otherwise, he will not know whether to plan for corresponding lead times to upgrade his measurement capabilities.

Also, a realistic knowledge of the limitations of measurements permits the systems engineer to specify and verify with greater confidence the RF properties of the interface for a component or subsystem so that devices produced in separate, specialized facilities operate satisfactorily and cooperate efficiently when assembled. The engineer needs higher confidence in the accuracy of RF measurements to facilitate economical mass production of systems utilizing the specialized skills of many suppliers. Excessive uncertainties result in uneconomical overdesign and often in overweight.

So much for why the engineer–user ought to know the state of the art. The extension of the art itself permits the exploration of new phenomena, and new phenomena, in turn, create new measurements. Examples of this interplay between measurements and research in an ascending spiral appear in radar technology, microwave spectroscopy, masers, and lasers.

For those who might think of working directly in the field, it is said that there are challenging frontiers and undeveloped areas in RF metrology and its application to mass production. For instance, the pursuit of accuracy in RF measurements requires the analysis of errors and the evaluation of limits of uncertainty. This is usually the most challenging aspect of this type of research since the measurement techniques themselves often are relatively straightforward. The solution of problems in radio metrology requires great skill, ingenuity, analytical ability, and perseverance on the part of the metrologist. Solid-state and atomic physics, circuit theory, electromagnetic theory, and advanced mathematics are used, and some problems require exceptional experimental ability. Radio-frequency metrology, urge the guest editors, needs both its artists and its scientists to produce excellent measuring instruments and the means to calibrate and evaluate them. Newcomers are wanted. (*Proceedings of the IEEE*, June 1967.)

Charge-Storage Diode Vidicon. A theoretical development that may have a significant impact on the vidicon camera tube art is reported in a current issue of the IEEE Transactions on Electron Devices. The author of the work, Paul H. Wendland, presents a theory for the design of junction diodes that can simultaneously exhibit high photosensitivity and a reverse-biased dark charge-storage time greater than $\frac{1}{30}$ second. His calculations have been specifically carried out for silicon and germanium photojunctions. The significance of the theory, which many readers of the Proceedings of the IEEE should especially appreciate, is that the charge-storage problem associated with the use of narrower-band-gap materials as vidicon targets is overcome. That is, a mosaic array of relatively small-band-gap, low-resistivity semiconductors could be used as the photosensitive target at or near room temperature.

Vidicons, which are well-known and widely used television camera tubes, use the phenomenon of photoconductivity to transduce light into electrical signals. It is particularly important that the relaxation time of the photoconductor be substantially greater than the $\frac{1}{30}$-second television raster scan time if a different signal is to be generated by the illuminated and nonilluminated regime of the target when they are scanned by the readout electron beam. In addition, a fast time response at all light levels is desired.

Wendland presents experimental data for single-element photojunctions in silicon, constructed according to the theoretical specifications for obtaining long-time dark-state charge storage. Wendland says that although a mosaic array of such junctions has not been fabricated, he believes it to be within the capabilities of state-of-the-art microelectronic technology. (P. H. Wendland, "A Charge-Storage Diode Vidicon Camera Tube," *IEEE Trans. on Electron Devices*, June 1967.)

Evolutionary Techniques. This issue of Spectrum features an article on the proposed development of evolutionary-type machines to enhance the control and perceptual skills of their human users. By contrast, the current issue of the IEEE Transactions on Systems Science and Cybernetics contains an article describing a specific evolutionary procedure, carried out by computer, to solve a traditional engineering problem.

The author calls attention to the recent interest in applying the principles of biological evolution to solve decision-oriented problems. To apply this principle, a competing *colony* of solutions, along with a test for survival and a means for reproduction, are necessary. Initially, a colony of solutions can be randomly created and, if necessary, adjusted to perform a certain function. After this stage, the solutions are compared according to some performance index and unsatisfactory ones eliminated. Finally, new solutions must be produced from mutations and from selective combinations of the remaining solutions.

The problem selected by the author to test the feasibility of evolutionary techniques has to do with process identification. Most present practical identification methods yield satisfactory approximations to most linear and to several nonlinear plants, but do not in general give good models for plants containing highly nonlinear or nonanalytic blocks such as saturation and dead zones.

The distinguishing characteristic of an evolutionary procedure for process identification is the dynamic competition among many models to optimize a performance index that relates their conformance with the process. Those models that do not satisfactorily duplicate the process characteristics are exterminated and those that perform satisfactorily are allowed to remain and reproduce. Thus, beginning with a randomly created colony of models, a satistically steady-state colony might be reached in which most members closely approximate the given process.

In this study, the author wrote computer programs to synthesize six competing models and programs to adjust, combine, and eliminate these according to their performance with respect to the actual process. He found that although the use of evolutionary techniques is promising for identifying processing having nonlinear and/or nonanalytic properties, it is also, at the present time, very costly with respect to computer time. The author concludes with some suggestions about future studies. (H. Kaufman, "An Experimental Investigation of Process Identification by Competitive Evolution," *IEEE Trans. on Systems Science and Cybernetics*, June 1967.)

Advance abstracts

The IEEE publications listed below are abstracted in this issue. The publications will be available in the near future. Information on prices may be obtained from IEEE, 345 East 47 Street, New York, N.Y. 11017. While IEEE does not stock copies of individual articles, photocopies may be purchased from the Engineering Societies Library at the above address.

Proceedings of the IEEE

Vol. 55, no. 9, September 1967

An Introduction to Computer Graphic Terminals, *M. H. Lewin*—The reader is introduced to some of the fundamental hardware and software aspects of typical CRT display consoles. Techniques for accomplishing display refresh are explained. The evolution of the CRT controller, from a device that simply includes a pair of digital-to-analog converters to a system that is a rather sophisticated, special-purpose hybrid processor (including analog function generators and digital control logic), is developed. Means by which a user generates display processor interrupts, particularly those associated with graphic input devices, are described. The use of electronic "pens" for user interaction with a display is then explained. Finally, the software structure for a typical graphic processor is discussed from a functional point of view. The linkage between a high-level symbolic picture description and the CRT "machine language" display file, via a set of generation subroutines, is described. The calling of picture modification programs by an interrupt analysis routine is also explained. Reasons for the need of a linked-list data structure are presented.

Surge Impedance, C. *F. Wagner*—In the conventional treatment of traveling waves on lossless lines, inductance and capacitance per unit length of line are used. Such treatment results in the usual concept of surge impedance and only certain aspects propagate with the velocity of light. The usual concepts of inductance and capacitance are defined in terms of their steady-state values. The treatment presented follows from electric field concepts in which the propagational time delays are taken into consideration through the use of retarded potentials. The current that flows is determined when a unit EMF is suddenly inserted in series in an infinitely long isolated conductor of zero resistance. The current equals the treatment surge admittance and its reciprocal is the transient surge impedance. The surge impedance increases with time in a determinable manner from a very small value. When such a conductor forms only the connecting leads to a pair of infinitely long parallel conductors, the surge impedance approaches the conventional value for the parallel lines.

The Rotator—A New Network Component, *L. O. Chua*—Discussed is a new linear, reciprocal, active two-port network element called a "rotator," of which there are three types: an *R*-rotator, an *L*-rotator, and a *C*-rotator. They have the unique property that whenever a nonlinear resistor, inductor, or capacitor is connected to one port of an *R*-, *L*-, or *C*-rotator, respectively, the resulting two-terminal network behaves as a new resistor, inductor, or capacitor whose characteristic curve is that of the original resistor, inductor, or capacitor, rotated by a prescribed angle about the origin. The rotator is realizable by either a π-network or a *T*-network of linear resistances, inductances, or capacitances. It can also be realized by a balanced lattice network of linear elements. Operational laboratory models are reported, and experimental data agree remarkably well with theoretical predictions. The sensitivity, power rating, and stability performances of rotators are considered in detail, and practical stability criteria are given. They are shown to be indispensable building blocks for realizing multivalued elements, and some potential applications are described.

Digital Measurement of Narrow-Band Noise Power, *M. E. Tiuri, S. J. Halme*—A digital measurement method for narrow-band noise power is described and analyzed in the case of flat spectrum Gaussian noise. Noise power is measured by counting the number of times the noise voltage crosses upwards a fixed voltage level. The method should be useful in noise-figure measurements, and by applying it a digital radiometer can be constructed. This digital radiometer has the same theoretical sensitivity (about nine percent worse than the best possible radiometer) as conventional radiometers now in use but offers several advantages in comparison with them. A switched digital radiometer is somewhat more sensitive to large gain variations than are normal switched radiometers.

High-Frequency Backscatter from Terrain with Trees, *J. G. Steele*—The standing-wave method was used to measure the radar cross section σ of a flat piece of ground on which stood a single tree. Measurements were made at 26 MHz at angles of elevation γ up to 22.5°, by raising the transmitting antenna with a balloon and moving the receiving probe along the transmitter-target line by means of ropes. For horizontal polarization, σ was a smoothly increasing function of γ. For "vertical" (polarization parallel to the plane of incidence on the ground), σ increased rapidly up to 10°, then became fairly constant with a value of 6 m². The sudden change in the slope of $\sigma(\gamma)$ is the knee effect suggested by previous observations. The Brewster angle was 14°, consistent with a theory that the knee should occur a few degrees below the Brewster angle. Below 15°, the cross section for vertical polarization was greater than that for horizontal polarization by as much as 30 dB.

A Self-Scanned Solid-State Image Sensor, *P. K. Weimer, G. Sadasiv, J. E. Meyer, Jr., L. Meray-Horvath, W. S. Pike*—An experimental television camera incorporating a completely integrated self-scanned solid-state image sensor has been built. The integrated sensor includes a photosensitive array having 32 400 picture elements, two 180-stage shift register scan generators, and associated video coupling transistors. This large-scale integration of more than 100 000 components was carried out in the laboratory entirely by evaporated thin-film techniques. Each element of the photosensitive array comprises one or two photoconductors of CdS or CdS-CdSe mixture, each in series with a diode. The 180-stage scan generators utilize 540 CdSe TFTs deposited upon a glass substrate. Center-to-center spacing of elements in the array and in the scan generators is 2 mils. The array is scanned at conventional television scan rates permitting the picture to be displayed upon a commercial television receiver. The camera is connected to the receiver either through a cable or through a UHF link with camera and transmitter powered by a self-contained battery. Camera circuits other than the integrated sensor employ conventional transistors and integrated components. Progress toward the development of an improved sensor having more picture elements is outlined.

Wide-Band Pulse Compression Via Brillouin Scattering in the Bragg Limit, *D. H. McMahon*—The optical characteristics of a pulse compression system using Brillouin scattering in the Bragg limit have been studied. It is found that the correct system geometry results in a bandwidth that is as large as simple diffraction theory predicts. The study shows that the bandwidth of the system, for maximum signal, is given by one half the total frequency sweep of the incident chirped pulse and that the expected dynamic range of signals that the system can reproduce is of the order of 10^4. The analysis also indicates how accurately the system parameters must be controlled to achieve the maximum compressed pulse signal.

Proceedings Letters

Because letters are published in PROCEEDINGS as soon as possible after receipt, necessitating a late closing date, we are unable to include a list here of the letters in the September issue of PROCEEDINGS. The list will appear in the next issue of SPECTRUM. Listed below are the letters from vol. 55, no. 8, August 1967.

High-Power Semiconductor Devices

Determination of the Current Distribution in Power Transistors by Use of Infrared Techniques, *R. J. Boncuk*

Turn-On Action in Large-Area Controlled Rectifiers, *D. W. Borst*

High-Voltage Thyristor Strings for Inverter Applications, *S. P. Jackson*

Silicon Power Zener Transient Suppressors, *O. Sturm*

Experimental Study of Avalanche Breakdown in Silicon Planar p-n Junctions, *P. R. Wilson*

High-Power High-Speed Silicon Transistor, *P. J. Kannam, D. A. Walczak, T. L. Chu*

Electromagnetics and Plasmas

The Fourier Transform of the Fields of Periodic Structures Excited by Aperiodic Sources, *R. A. Sigelmann*

Mean Radar Cross Section of Finite Cylindrical Wires: Dependence on Conductivity and Frequency, *A. Mayer*

The *Z*-Transform and Unequally Spaced Arrays, *M. I. Spellman, B. J. Strait*

Wave Propagation in a Stratified Compressible Magnetoplasma with a Static Pressure Gradient, *R. Burman*

Comment on "Potential Equations for Anisotropic Inhomogeneous Media," *V. P. Pyati, B. R. Chawla, H. Unz*

Circuit and System Theory

A Limitation of Power Consumption, *F. M. Reza*

Gain Saturation in Crystal Mixers, *P. Torrione*

Linear Operators and Reciprocity, *F. M. Reza*

Lumped Equivalent Circuits of an Exponential *RC* Line, *M. N. S. Swamy, V. Ramachandran, B. B. Bhattacharyya*

Electronic Circuits and Design

Nonlinear Effects of Negative-Resistance Amplifiers on Signals, *R. O. Harger, D. J. Lewinski*

Design of Resistance-Capacitance Null Networks, *V. Ramachandran*

Electronic Devices

Field-Effect Control of Conductance in ZnO and Its Application to Image Storage, *B. Kazan, J. S. Winslow*

Further Observations Above and Below Twice the Gunn Threshold, *P. L. Fleming*

Charge Storage in Metal-Silicon Nitride-Silicon Capacitors, *C. L. Hutchins, R. W. Lade*

Microwave Conductivity Anisotropy of Hot Electrons in n-InSb at 77°K, *H. W. Pötzl, K. Richter*

The Influence of a Transverse Electric Field on Helicon Wave Propagation in InSb at 35 GHz, *F. Seifert, H. W. Pötzl*

Comments on "Gate Leakage Currents in MOS Field-Effect Transistors," *V. C. Negro, E. J. Kennedy*

A Perturbation Method for Including Losses in the Analysis of Varactor Harmonic Generators with Idler, *J. I. Smith*

Analysis of the Effect of Charge Storage on the Frequency Response of SCRs, *H. J. Kuno*

Up-Conversion with Gunn-Effect Diode, *S. Sugimoto*

Firing Sensitivity of Thyristors—Response Time, *E. Y. Rocher, R. E. Reynier*

Rieke Diagrams for Avalanche Diodes Show Performance as a Function of Load, *E. M. Davis*

A New Optically Read Ferroelectric Memory, *S. E. Cummins*

A New Bistable Ferroelectric Light Gate or Display Element, *S. E. Cummins*

Optics and Quantum Electronics

InSb-GaAsP Infrared to Visible Light Converter, *R. J. Phelan, Jr.*

A Laser-Triggered 50-pps High-Voltage Switch with Nanosecond Jitter, *A. H. Guenther, R. H. McKnight*

Film Resolution and Holographic Recordings, *D. J. Stigliani, Jr., R. G. Semonin, R. Mittra*

A Technique for Bandwidth Reduction in Holographic Systems, *K. A. Haines, D. B. Brumm*

Power Scintillations Due to the Wandering of the Laser Beam, *R. Esposito*

The Probability Density of Light Energy from Photoelectric Measurements, *M. J. Pioroso, L. P. Bolgiano, Jr.*

Automatic Display of Large-Signal Instantaneous Impedance of Microwave Diodes, *J. M. Osterwalder*

Correction to "A Computer Algorithm for the Synthesis of Spatial Frequency Filters," *J. J. Burch*

Communication Theory

Sequential Detection of Constant and Slowly Fading Signals, *N. D. Wallace*

The Correspondence of Intermodulation and Cross Modulation in Amplifiers and Mixers, *B. Ebstein, R. Huenemann, R. Sea, W. R. Gretsch*

Computers

A Word-Organized Continuous Film Memory, *K. Goser*

Comments on "All Paths Through a Maze," *A. Guzmán, H. V. McIntosh, D. Kroft*

Communication Technology

More Comments on Phase-Locked Loop Threshold, *R. I. Ridgway, J. E. Carter*

Miscellaneous

Magnetoacoustic Delay Line Employing YIG-YAG-YIG Configuration, *J. H. Collins, D. C. Webb*

Higher-Order Terms in the Saddle Point Approximation, *R. H. Schafer, R. G. Kouyoumjian*

Stability Analysis of Neuristor Waveforms, *R. D. Parmentier*

Detection of Transposition Errors in Decimal Numbers, *H. Freeman*

Hamilton's Principle for Linear Piezoelectric Media, *H. F. Tiersten*

On Variational Techniques for Piezoelectric Device Analysis, *E. P. EerNisse, R. Holland*

IEEE Transactions on Antennas and Propagation

Vol. AP-15, no. 5, September 1967

Design of Dielectric-Covered Resonant Slots in a Rectangular Waveguide, *M. C. Bailey*—A summary is given of the effects of a dielectric cover upon the resonant frequency, the resonant conductance of a longitudinal shunt slot, and the power coupled out of a waveguide by a pair of near circularly polarized crossed slots. Typical data curves are presented that illustrate these changes due to variations in the dielectric constant and thickness of the cover. A simple modification of Stevenson's free-space theory for resonant slots radiating into a homogeneous dielectric half-space is used in conjunction with the plane-wave reflection coefficient to predict bounds on the conductance and power variations for dielectric thicknesses greater than about one-quarter wavelength. The accuracy of this simple theory in predicting measurements on dielectric-covered slots is similar to the accuracy of Stevenson's free-space theory within about 9 percent for the shunt slots and about 15 percent for the cross slots.

Radiation from an Infinite Aperiodic Array of Parallel-Plate Waveguides, *S. W. Lee*—The problem of radiation from an infinite array of parallel-plate waveguides with an arbitrary number of the guides being short-circuited is considered. By Wiener–Hopf techniques, the reflected field in the waveguides and the radiated far field in the empty half-space are obtained. The results are then applied to evaluate the "edge effect" of a finite array through numerical examples.

An Experimental Study of the Antenna with Nonreflecting Resistive Loading, *L. C. Shen*—The current amplitude, input admittance, and radiation field pattern of a dipole antenna with a step-function internal impedance were measured in the UHF range and compared with theory. The zero-order theory gives accurate descriptions of the current distribution, the field pattern, the wide-bandwidth property, and the existence of the traveling wave on the antenna. The agreement in the input admittance is not good, but it can be improved with the help of the variational principle. The field pattern of this resistive antenna when displayed as a 90° V-antenna was found to be directional and insensitive to changes in frequency.

Antenna Arrays with Partially Tapered Amplitudes, *B. J. Strait*—A new technique is presented for linear array design based on a form of limited amplitude tapering. It is shown that desirable pattern characteristics can be achieved using an amplitude distribution that is uniform over all but a few of the outermost pairs of array elements, resulting in a partially uniform array. This method applies equally well to broadside and endfire arrays, and can be used to place pattern nulls in one or more specified directions or to eliminate virtually all radiation over one or more sectors of space. When compared with Dolph–Chebyshev arrays corresponding to the same sidelobe levels, partially uniform arrays provide a simpler excitation scheme in general and, in some cases, higher directive gain and a lower maximum-to-minimum excitation ratio. Both theoretical and experimental examples are given.

The Quasi-Near Fields of Dipole Antennas, *P. R. Bannister*—The electric- and magnetic-field components produced by vertical and horizontal dipole antennas (both electric and magnetic types) located over, on, or below the surface of a semi-infinite conducting medium are derived and presented for the quasi-near range. (The measurement distance is much greater than an earth skin depth, but much less than a free-space wavelength.) Previously derived results are briefly summarized. The horizontal separation ρ between the transmitting and the receiving dipole antennas is comparable to their heights. The derivations are the result of applying the quasi-near approximations to the basic Sommerfeld integrals and, in some cases, utilizing the reciprocity theorem. When ρ is much greater than the antenna heights, the formulas for the field-component expressions reduce to previously derived results. It is observed that some of the field-component expressions are characterized by unusual height gain (or loss) functions. Some numerical values for these functions are provided.

The Admittance of a Rectangular Waveguide Radiating Into a Dielectric Slab, *W. F. Croswell, R. C. Rudduck, D. M. Hatcher*—The variational analysis of Compton is modified to account for the surface-wave pole contribution to the admittance of a waveguide-fed slot on a ground plane covered with a low-loss dielectric slab. The results of an extensive experimental study to determine the effects of ground plane and dielectric slab size upon waveguide admittance are compared with calculations using the dominant waveguide mode field as a trial solution. It is found that a waveguide terminated in a flat flange is of sufficient size to approximate the infinite ground plane assumed in the theory. A disagreement of 20 percent was noted for some thin-sheet cases. Based upon a thorough theoretical and experimental investigation, it was concluded that tolerances do not explain the error; however, a measurement of the aperture field for cases where maximum error occurs reveals significant distortions. Hence, it is concluded that induced higher-order modes are the probable cause of disagreement.

Theory of Equiangular-Spiral Antennas. Part I—Numerical Technique, *Y. S. Yeh, K. K. Mei*—The integral equation method is applied to find the rigorous solutions of the current distributions on conical, equiangular-spiral antennas of arbitrary spiral parameter and cone angle. With a transcendental interpolation function, antennas up to 10λ in arm length can be calculated. Comparisons of calculated and experimental results are presented, indicating excellent agreement. The computer programming resulting from this investigation thus replaces painstaking procedures of design, experimentation, and optimization of equiangular-spiral antennas by a few minutes of computer calculations.

A Line Feed for a Spherical Reflector, *G. C. McCormick*—A line feed for a spherical reflector is considered on the basis of a plane-wave spectrum of radiation angles. It is shown that a feed excited by circumferential slots results in a gain deterioration of at least 3 dB. The correct excitation of the feed is indicated. Expressions for field components in the focal region are obtained.

Asymptotic Theory for Dipole Radiation in the Presence of a Lossy Slab Lying on a Conducting Half-Space, *J. R. Wait*—The basic theory for dipole radiation in the presence of a two-layer half-space is outlined with special reference to its use as a model for studying radio propagation through and over heavily vegetated terrain. The source dipole may be located above or below the top surface of the slab. The dipole orientation is either vertical or horizontal. The asymptotic derivations for the field expressions are carried out without making the usual assumption that the refractive index of the uppermost layer is large compared with unity. The final results exhibit the expected inverse square dependence of the fields on horizontal range.

Behavior of Non-Rayleigh Statistics of Microwave Forward Scatter from a Random Water Surface, *C. I. Beard*—Measurements of the phase-quadrature components of the microwave field forward-scattered from random water waves have continued since the observance in 1963 of non-Rayleigh probability distributions of the incoherent scattered field. Measurements of the variances of the phase-quadrature components of the incoherent field at various phase angles with respect to the coherent field have yielded new results not explained by plane-wave theory: (1) The equiprobability ellipse of the phase-quadrature components of the incoherent field rotates as a function of apparent surface roughness. (2) The rotation of the equiprobability ellipse varies more rapidly with roughness for "narrow" surface illumination and less rapidly for "broad" illumination. (3) The greatest ratio of the two variances appears to rise from unity with increasing roughness to a peak value (maximum departure from Rayleigh), and presumably decreases at greater roughnesses. The data indicate that nonplanar illuminating and receiving wavefronts may be responsible for these divergences from plane-wave theory.

Reduction of Scattering Cross Section of Dielectric Cylinder by Metallic Core Loading, *J. C. Sureau*—The criteria for minimization of the total scattering cross section of a metal-core-loaded dielectric circular cylinder for parallel polarization are discussed. The rigorous expression for the scattered field in terms of cylindrical harmonics is expressed in forms suitable for computer or hand calculation. The phenomena by which a reduction in cross section is obtained are interpreted as resonances for which exact conditions are given. It is shown that when the diameter is less than half the wavelength in the dielectric, the condition that minimizes the cross section is the cancellation of the monopole term in the harmonic series expansion. For larger diameters, the optimum condition corresponds to a compromise between cancellation of the first term and higher-order terms. Design curves are provided over the pertinent range of parameters.

On Higher-Order Diffraction Concepts Applied to a Conducting Strip, *J. S. Yu, R. C. Rudduck*—The derivation emphasizing cylindrical-wave diffraction is given for a high-frequency approximation to the diffraction of a plane wave by a conducting strip. The resulting formulation is basically the same as the formulations of Karp and Russek. The range of usefulness of this formulation has apparently been unrecognized. The validity of the approximation presented here is checked by comparison with the exact solution for strip diffraction; the backscattered field for normal incidence is in good agreement for strip widths larger than 0.55λ and in fair agreement for widths as narrow as 0.125λ. This approximation and Keller's geometrical theory of diffraction, which uses plane-wave diffraction coefficients, are compared with measurements made by Ross. Diffraction patterns and echo widths for various incidence angles are calculated for various strip widths.

Geometrical Shadowing of a Random Rough Surface, *B. G. Smith*—In the context of the backscattering of waves from a random rough surface, a theoretical model is used to investigate the geometrical self-shadowing of a surface described by Gaussian statistics. Expressions are derived for various shadowing probabilities as functions of the parameter characterizing surface roughness and of the angle of incidence of the illuminating beam. The theoretical shadowing functions compare closely with those obtained experimentally from a recent computer simulation of a Gaussian surface.

Surface Waves on a Grounded Dielectric Slab Covered by a Periodically Slotted Conducting Plane, *R. A. Sigelmann*—The surface-wave modes in a dielectric slab covered by a periodically slotted conducting plane are investigated. Two methods—sampling and variational—are used to obtain the surface-wave modes. The dispersion curves obtained by the two methods agree very well. The experimental and the theoretical results are in good agreement, except close to the stopband.

Scattering from Inhomogeneous Plasma Spheres in the Collisionless Approximation, *E. Buley*—The scattering of electromagnetic radiation from overdense inhomogeneous plasmas in the collisionless approximation is discussed, with a radially varying plasma sphere used as illustration. It is shown that the electric field is singular at points where the local plasma frequency is equal to the incident frequency. In addition, it is shown that absorption takes place even in this limiting case, which cannot be ignored if the approximation is to be valid.

Measurements of Dipole Antenna Impedance in an Isotropic Laboratory Plasma, *K. A. Graf*—The impedances of relatively long dipoles in an isotropic laboratory plasma have been measured at 9.2 GHz (X band). A helium plasma was generated by discharging a capacitor between electrodes in a cylindrical container ten free-space wavelengths in diameter. Impedance measurements were made in the decaying afterglow plasma at electron densities both above and below the critical electron density (10^{12} cm^{-3}). The dipole antennas were fed from miniature solid-jacketed coaxial cables attached to a waveguide on which the voltage reflection coefficient was measured. The effect of plasma on the impedance of the dipole antenna was derived theoretically by treating the dipole as a dissipative transmission line. The theory described in a qualitative fashion the observed impedance variation with electron density for all the dipoles investigated. The measurements indicated certain antenna impedance properties, due to the plasma, which were not accounted for by the simple theory.

Communications

A Simple Approximate Formula for Effective Length of Linear Receiving Antennas, *J. Surutka, B. Popovic*
On the Properties of a Wave Reflected from a Converter Array, *W. M. Waters*
A Note on Reflector Arrays, *H. Kurss, W. K. Kahn*
Shunt-Feeding the Moderately Superdirective Normal-Mode Helix, *D. T. Stephenson, P. E. Mayes*
An Interative Solution of Fredholm Integral Equations of the First Kind, *C. D. Taylor, E. A. Aronson*
Matrix Methods for Solving Antenna Problems, *E. A. Aronson, C. D. Taylor*
Discussion, *R. F. Harrington*
A Parasitic End-Fire Array of Circular Loop Elements, *J. E. Lindsay, Jr.*
Graphical Aids for Polarization Problems, *P. Beckmann*
Radiation Influence Coefficient, *S. Sensiper*
A Representation of Cylindrical Antennas for Manpack Installation, *A. Rashid*
On the Measurement of a Bifilar Complementary Helical Antenna, *P. R. Wu*
Radio Propagation Over a Gaussian Shaped Ridge, *L. A. Berry*
On Coherent Detection of Scattered Light, *T. S. Chu*
An Asymptotic Field Calculation in the Penumbra Region, *B. Rulf*
The Distortion of Electromagnetic Pulses Undergoing Total Internal Reflection in a Stratified Troposphere, *J. S. Nicolis*
Phase of the Electromagnetic Field on the Surface of an Inhomogeneous Earth for Sky-Wave Illumination, *J. R. Wait, K. P. Spies*
Scattering by Edges: The Hemisphere, *S. D. Weiner*
Antenna Plasma Interaction in a Conical Geometry, *R. Kristal, P. Shizume*
Plasma Antenna in a Nuclear Environment, *R. N. Ghose*
Dielectric Spheroid in Anisotropic Medium Under the Influence of Uniform Field, *V. P. Pyati*
On Wave Propagation Along a Plasma Slab, *D. K. Sarkar, K. E. Lonngren*
Further Comment on "Microwave Propagation over Mountain-Diffraction Paths," *A. T. Waterman, Jr., A. B. Carlson*

IEEE Transactions on Audio and Electroacoustics

Vol. AU-15, no. 3, September 1967

Speech-Processing Techniques and Applications, *H. F. Olson, H. Belar, E. S. Rogers*—The processing of speech involves the analysis, coding, decoding, and synthesis of speech sounds. The speech analyzer consists of normalizers, syllable and syblet segmenters, sound recognizers, sequencers, adapters, and memories that convert the speech elements into a code. The speech synthesizer converts the code to speech by reproducing prerecorded speech elements. There are many applications for the speech analyzer and synthesizer, ranging from limited vocabulary to complete communication systems.

Experimental, Limited Vocabulary, Speech Recognizer, *C. F. Teacher, H. G. Kellett, L. R. Focht*—An experimental speech recognizer is described that exhibits a high level of performance and is practical in terms of size, weight, cost, and power consumption. High recognition performance is achieved by employing the limited vocabulary approach and utilizing a simple set of parameter extractors based upon the single equivalent formant theory conceived and developed by one of the authors. Recognition logic for a vocabulary word consists of circuitry for testing the levels and movements of three parameter waveforms to determine whether they conform to the conditions of acceptability for the particular word as found from parameter data for a large number of speakers. The recognizer presently responds to the spoken digits "oh" through "nine" with a recognition accuracy of 90 percent and an error rate of one percent on live utterances by speakers who contributed the design samples, and only slightly lower than this on other male speakers of similar speech characteristics. The recognizer occupies a volume of less than 0.8 cubic foot exclusive of microphone, indicator, and power supplies, consumes less than 30 watts, and shows promise of a very low eventual cost per word.

Systems for Compressing the Bandwidth of Speech, *B. Gold, C. M. Rader*—Speech bandwidth compression is based on what the authors know about human speech production and perception. This is the first in a series of papers reviewing the articulatory, acoustic, and network description of speech; it discusses the bandpass compressor, which is a simple example of a bandwidth-saving device.

The Squad Radio Exponential Horn and Driver, *D. S. Morris, D. E. Brinkerhoff*—The effectiveness of the helmet-mounted Squad Radio AN/PRR-9 in a battlefield environment is largely determined by the capability of the receiver to deliver adequate sound power to the ear of the user without impairing his ability to hear sounds around him. During the development of the Squad Radio receiver conducted by the U.S. Army Electronic Research and Development Laboratories in conjunction with the Delco Radio Division of General Motors, emphasis was placed on finding a solution to this problem. High audio power could not be used to provide necessary sound power levels due to the size, weight, and battery drain limitations of the receiver. Therefore, effort was placed in optimizing the efficiency of conversion of electrical audio power to acoustical power. The result of this effort is a low-cost, compact, lightweight exponential horn–driver unit that will provide enough sound power to the user's ear to overcome anticipated battlefield noise. A computer program was used to analyze and optimize the driver and horn parameters for this application. Detailed requirements of the horn–driver unit are discussed, as well as the methods used in its development, and the performance of the final units.

Correspondence

An Acoustical Application of the Logarithmic Transformation to a Normally Distributed Random Variable, *D. C. Gause*

IEEE Transactions on Bio-Medical Engineering

Vol. BME-14, no. 4, October 1967

Parametric Sensitivity of Physiological Systems—Prognostic Analysis, *R. E. King*—Prognostic analysis is a procedure for studying a broad class of multivariable dynamic physiological systems with respect to parametric changes. The technique is basically an application of sensitivity analysis and leads to a computer method for extrapolating the observed behavior of a system for a range of parametric deviations about their nominal values due to operational malfunctions. The essentials of the technique, indirectly related to diagnosis, are presented, and examples of its application are given.

Dielectric Properties of Osmium-Fixed Erythrocytes, *E. L. Carstensen, R. W. Smearing*—The deterioration of the membranes of osmium-fixed erythrocytes after washing in distilled water is demonstrated by a marked drop in membrane resistance and an increase in permeability of the cells to small solute molecules. Yet when these cells are placed in dilute salt solutions, their conductivity remains high. The lower limit of the cell conductivity is presumably determined by the counterions of the fixed charges within the cell. Both the stability of the membrane and the fixed charge concentration within the cell are found to depend upon the pH of the fixing solution used for preparation of the cells.

The Effect of Prior EEG "Coupling" Upon the Visual Evoked Response, *G. C. Galbraith*—A unique statistical technique is described that appears to measure important interaction processes within the central nervous system (CNS). This statistic, termed "weighted-average coherence," or $\bar{C}$, is derived primarily from parameters generated in cross-spectral frequency analysis. $\bar{C}$ has the useful property, however, of summarizing a larger amount of cross-spectral information into a more manageable form. By applying $\bar{C}$ analysis to the ongoing electroencephalogram (EEG) it has been possible to define unique patterns of interaction, or "coupling," between different brain areas. The total pattern of EEG coupling is taken to define a given state of functional brain organization. Moreover, since $\bar{C}$ is sensitive to changes in the EEG, it also reflects something of the dynamic properties of such brain organization. Multiple EEG signals were recorded from a rhesus monkey with chronically implanted electrodes. Ongoing EEG activity recorded just prior to a sensory stimulus (light flash) was submitted to an extensive computer analysis in order to determine EEG coupling relationships. Results showed that such preceding brain coupling exerted a marked effect upon the subsequently occurring visual evoked response. These results support the meaningfulness of $\bar{C}$ as a measure of functional brain organization and also provide a basis for understanding how such organization is effected in the CNS.

The Design and Use of an FM/AM Radiotelemetry System for Multichannel Recording of Biological Data, *J. R. Zweizig, R. T. Kado, J. Hanley, W. R. Adey*—A multichannel telemetry system for EEG recording has been constructed for study of animal or human behavior correlates under natural, unrestrained conditions. To be useful in research of this kind, the transmitted radio signal must be independent of the environment, so that changes in antenna loading and in signal level cause no artifact. Standard IRIG proportional-bandwidth FM subcarrier channels are used. These subcarriers are generated by twin-T oscillators, modulated in turn by the amplified data signals. The FM subcarriers are then linearly summed and impressed upon a crystal-controlled AM transmitter. The system is also relatively insensitive to major shifts in supply voltage. Wherever possible, fabrication was by means of integrated circuits, thus reducing the bulk of the modules. When used in conjunction with appropriate sensing electrodes, this system yields accurate records, with subjects both at rest and in motion, and for recording periods as long as 24 hours. Electrical seizure data were obtained in situations where an observer looking for the typical tonic or clonic contractions would have missed the pathological brain activity, since there were no associated motor signs. Recordings of longer duration than usual are possible due to increased freedom of movement by the subject.

Magnetic Susceptibility Meter for In Vivo Estimation of Hepatic Iron Stores, *J. H. Bauman, R. W. Hoffman*—An instrument is described for recording linear body scans of magnetic susceptibility in living rats. The sensor is a transformer that employs a toroid core with a large air gap. The magnetic properties of substances within the gap affect the reluctance of the core-gap magnetic circuit, thereby affecting the transformer characteristics. To minimize instability caused by temperature-induced changes in core dimensions, the cores were made of the low-expansion steel, Invar. The secondary voltage of the measuring transformer is compared with that of a similar reference transformer with differences in this comparison voltage processed by tuned amplification and phase-sensitive detection. The sensitivity of the instrument is limited by zero instability equivalent to $\pm 0.06 \times 10^{-6}$ EMU/cm^3 over 30 seconds with a precision of measurement of $\pm 0.03 \times 10^{-6}$ EMU/cm^3 achieved by output filtering. Studies using live rats demonstrate that with this technique iron-loaded animals can be distinguished from control animals because the high hepatic concentration of storage iron in the liver of the experimental group exhibits positive magnetic susceptibility. Consideration of the transformer characteristics suggests that similar, safe, and rapid measurements of magnetic susceptibility can be made in humans, although many other factors remain as variables that must be evaluated before such measurements can be used to quantitate iron stores in patients.

A General Approach for Computation and Interpretation of Dilution Curves, *J. Melbin*—A short appraisal is made of computerized methods utilized in the evaluation of dilution curves. Based on requirements of experimental and clinical studies, a general on-line real-time approach is proposed that increases information retrieval from standard curves. A simple, hybrid scheme tests for exponential or other declines if desired. The point for curve extrapolation is determined by the test, which also controls the character of the extrapolated curve. Information obtained from the test itself can define characteristics of the decline and thereby yield insight into the character of the system itself. As it tests for the desired reference regardless of variations in indicator curves, the technique offers both precision and accuracy. It is adaptive, in that individual needs can be satisfied by adding tests, and/or monitoring checks, and/or adjusting coefficients. Approximations to required extrapolations can be made at the discretion of the user. A particular configuration is presented that tests for exponential decline. If decline is not exponential, as has been experienced in absence of recirculation, the procedure computes the actual curve without substitution.

Computer Equalization of Low-Frequency Components in Tape-Recorded Electrocardiographic Signals, *R. C. Arzbaecher, M. D. Woolsey, D. A. Brody*—Low-frequency equalization of a digitized electrocardiographic waveform has been accomplished by adding to the waveform several of its integrals, appropriately weighted. The weighting factors required for correction of distortion produced by a particular amplifier are initially obtained from a least-squares correction of its step response. Neither analysis of the amplifier circuit nor frequency-response testing is necessary.

Cross-Correlation Techniques Applied to the Electrocardiogram Interpretation Problem, *G. J. Balm*—A study was made to see if a single, easily recorded electrocardiogram lead can be used—employing a cross-correlation scheme—to screen abnormal adult ECG waveforms from normal waveforms. The study also sought to classify the abnormal waveforms into their respective disease categories. Standard lead *I* (the potential from left to right arm) was chosen for the study. Only the QT interval, the part of the heart cycle resulting from the electrical activity of the ventricles, was studied. In addition to "normal" ECG waveforms, four cardiac diseases were studied: right and left bundle branch block and right and left ventricular hypertrophy. Studies were made to determine the required sampling rate, the time and amplitude normalization procedures, the selection of standard waveforms to represent various waveform categories, and the classification method. Computer-run cross-correlations indicate that abnormal waveforms (at least those representing the studied diagnoses) can be reliably screened from normal waveforms, but more than one electrocardiogram lead waveform is needed to distinguish a broad spectrum of heart diseases and classify them into their respective disease categories.

Short Communications

Biological Electrical Power Extraction from Blood to Power Cardiac Pacemakers, *M. E. Talaat, J. Kraft, R. A. Cowley, H. Khazei*

Filling of Micro-Pipette Electrodes for Intracellular Recording, *H. van den Ende*

IEEE Transactions on Broadcasting

Vol. BC-13, no. 4, October 1967

How Many Channels? Perspective on Some New Challenges for Broadcast Engineers and Managers, *D. G. Fink*

Single-Sideband Distortions of NTSC Color Signals Due to Envelope Detection, *N. W. Bell*—It is pointed out that envelope detection of single-sideband signals produces distortion under some conditions. The color information in the NTSC system is transmitted as a single sideband. One effect of the distortion is to change the saturation of colored areas. The change in saturation is calculated for a standard color-bar signal.

A Study of the Use of High-Power Medium-Wave Broadcasting Transmitters in the European Area, *A. S. W. Kershner*—An engineering study has been made of the use of high-power transmitters for providing medium-wave broadcasting service in Europe and the nearby areas of North Africa and the Middle East. The purpose of the study is to acquaint U.S. broadcasting engineers with the experience and problems that have resulted from medium-wave broadcasting allocations and operations in the European area in recent years. The Clear Channel stations operating in the United States have, for some time, recommended the use of transmitter powers considerably higher than the present maximum limit of 50 kW set forth in the FCC Rules. Only limited experimental operation with high power has been permitted in the United States and it is thus considered to be of interest to examine the results obtained with high-power broadcasting in Europe.

Television Interlace Pairing: Its Effect on Detail Response and Its Measurement, *W. L. Hurford*—The loss in detail response that results from pairing in the camera and/or the monitor is investigated. It is shown that there are two components of degradation of the detail response. One is due to the displacement of one part of the image on one field relative to the rest of the image in the other field. This relative displacement causes a loss in detail response at all line numbers. The other component is a truncation of the detail response due to the inefficient sampling, when the sampling interval is nonuniform. Measuring methods for the determination of percentage pairing in both camera and monitor are suggested. These methods include both qualitative evaluation and quantitative measurement.

IEEE Transactions on Circuit Theory

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Compensation of Parastic Capacitances in Broadband Filters, *J. Neirynck*—Methods are presented to anticipate the effect of the coils' parasitic capacitances in the implementation of broadband filters. The case of uniform parasitic capacitances leads to a process that is in some respect analogous to the classical predistortion theory for losses: the compensation problem can be solved by operating solely on the transmittance function. Limits of realizability, independent of the filter structure, have been found for the cases of finite terminations and short-circuited output. In the case of nonuniform capacitances, methods are described to generate equal shunt capacitances and to equalize the values of the inductances. A numerical example has been treated that allows a comparison of the various methods described.

A Study of Recurrent Ladders Using the Polynomials Defined by Morgan-Voyce, *M. N. S. Swamy, B. B. Bhattacharyya*—The matrix parameters of a recurrent ladder network with general series and shunt arms are derived in terms of a set of polynomials, which were first defined by Morgan-Voyce in his studies of the special case of a resistive ladder. Since the polynomials are factorizable, the matrix parameters can be conveniently utilized to yield network response to any given excitation. Also, the zeros and poles of any network function may be found in terms of the zeros of these polynomials. For purposes of illustration, response to a square-wave input has been worked out in detail in the case of an *RC* ladder. The chief merit of the analysis lies in its simplicity and compactness.

On the Realization of a Constant-Argument Immittance or Fractional Operator, *S. C. Dutta Roy*—Methods for realization of an immittance whose argument is nearly constant at $\lambda\pi/2$, $|\lambda| < 1$, over an extended frequency range, are discussed. In terms of the generalized complex frequency variable s, these immittances are proportional to s^λ and, as such, they are approximations of Riemann–Louville fractional operators. First, a method that is applicable for the special case $|\lambda| = ½$ only is presented. This is based on the continued fraction expansion (CFE) of the irrational driving-point function of a uniform distributed *RC* (URC) network; the results are compared with those of earlier workers using lattice networks and rational function approximations. Next, two methods applicable for any value of λ between -1 and $+1$ are discussed. One is based on the CFE of $(1 + s^{\pm 1})^{\pm\lambda}$; the two signs result in two different circuits that approximate $s^{-\lambda}$ at low and high frequencies respectively. The other method uses elliptic functions and results in an equiripple approximation of the constant-argument characteristic. In each method, the extent of approximation obtained by using a certain number of elements is determined by use of a digital computer and the results are given in the form of curves of ω_2/ω_1 versus the number of elements, where ω_2 and ω_1 denote the upper and lower ends, respectively, of the frequency band over which the argument is constant to within a certain tolerance. From the lumped element networks, we derive some $\overline{RC}$ networks that can approximate s^λ more effectively than the lumped networks. The distributed structures can be fabricated in microminiature form by the use of thin-film techniques and should be more attractive in terms of cost, size, and reliability.

Parallel Interconnection of n-Port Networks, *A. Lempel, I. Cederbaum*—Parallel interconnection of n-port networks without transformers is considered, and a necessary and sufficient condition is given under which the short-circuit admittance matrix (Y matrix) of the resultant n port is equal to the sum of Y matrices of the component n ports. The given condition applies to nonsingular n-port networks containing a finite number of linear, lumped, and reciprocal R, L, and C elements. A possible application of the results to the *RLC* n-port synthesis problem is indicated.

The Existence of a Hamilton Circuit in a Tree Graph, *T. Kamae*—The existence of a Hamilton circuit in a tree graph was first proved by R. L. Cummins. However, his proof is hard to apply to the generation of all the trees in a given graph. The new proof is straightforward and concise, and also constructive and applicable to the tree generation. The outline of a tree generation procedure is shown.

Number of Trees in a Cascade of Two-Port Networks, *B. R. Myers*—Recurrence formulas for the numbers of trees, port terminal-pair two-trees, and terminal three-trees in a cascade of nonidentical two-port networks are presented. They are derived from counting series that provide a clear insight, not apparent from the recurrence formulas themselves, into the composition of the various tree structures. These formulas and series reduce readily to the simpler forms that pertain when the networks in the cascade are identical, confirming certain recurrence formulas presented previously by Gruszczynski for this special case.

Microwave Networks with Constant Delay, *J. O. Scanlan, J. D. Rhodes*—A general class of transfer functions whose delay is constant at all frequencies, and capable of realization by commensurate TEM microwave networks, is presented. Examples of this class where the transducer power gain has equiripple behavior in the passband, the stopband, or both, are given, and forms suitable for low-pass or bandpass filters, or broadband matching transformers are derived. The synthesis of networks to realize all of these functions is given in terms of closed formulas for the necessary roots. In general, microwave Brune, *C* and *D* sections are required in the realization.

Transmission-Line Filters Approximating a Constant Delay in a Maximally Flat Sense, *T. A. Abele*—An exact method is presented to find transmission factors of transmission-line filters that approximate a constant delay in a maximally flat sense. The class of filters considered is a doubly loaded arbitrary cascade of transmission lines and open- or short-circuited stubs in series or in shunt, all elements being of equal length and nondispersive. This includes a variety of transmission-line filters: $\lambda/4$ transformers, distributed low-pass filters, stub filters of various configurations, interdigital filters, etc. Explicit expressions, valid for any order n of the filter, are derived for the normalized transmission factor and for its squared magnitude and its phase on the imaginary axis. In addition, a table and design curves are provided for the cases $n = 2, 3, 4,$ and 5 and an example is given to demonstrate their use.

Network Topology and Stability of Time-Varying RLC Networks, *T. Murata*—A topological formulation of Liapunov stability conditions for linear and nonlinear time-varying *RLC* networks is presented. In other words, Liapunov stability theorem for linear time-varying *RLC* networks obtained by Kuh is formulated in terms of the tree or chord-set products of the subnetworks derived from the state-space representation of the networks and the same approach is extended to the local stability of nonlinear time-varying *RLC* networks. The new formulation provides stability information or stability criteria in terms of network elements for linear and nonlinear time-varying *RLC* networks by inspection of topology and network elements. The formulation is illustrated in detail by the use of examples.

Steady-State Analysis of Linear Networks Containing a Single Sinusoidally Varying Capacitor, *J. V. Adams, B. J. Leon*—A method is presented for analyzing linear time-invariant networks containing a single sinusoidally varying capacitor. The method is based on difference equations, and yields an explicit expression for the steady-state response. Error bounds are given whenever approximations are made. A numerical example is included in order to compare the method presented with the harmonic balance method.

Exact Results for a Parametrically Phase-Locked Oscillator, *R. F. Keenan*—An exact expression for determining the form and stability of solutions of the second-order linear differential equation governing a simple tuned circuit with square-wave variable conductance is derived. This expression is numerically evaluated to provide mode and stability diagrams particularly relevant to applications wherein it is desired to generate oscillations that are phase-locked to an external signal and experimental verification of some of the data is given. Relative to nonlinear-element approaches to the synthesis of phase-locked oscillators, the principal advantage of the present method would appear to be that the locking-range accuracy and the condition for oscillation do not rely upon a particular nonlinearity but, instead, on the extent to which a square wave can be generated. Depending on the application, one disadvantage may be that, in contrast to the results that have been obtained for previous special-variation cases of Hill's equation, it is difficult to lock the oscillator frequency to an even integral multiple of one half the pump frequency.

Characterization of Noise Performance of Pumped Nonlinear Systems, *V. K. Prabhu*—An attempt has been made to define exchangeable amplitude and phase noise powers for pumped nonlinear systems. The idea of cascading of linear lossless networks has been introduced for this purpose. Meaningful noise figures for the pumped nonlinear systems have been defined by comparing output parameters with source parameters. This definition of noise figures has the distinct advantage that the figures that the author has thus defined are invariant to any additional linear lossless transformations the user may wish to employ.

Darlington Pulse-Forming Network, *H. F. Mathis, R. F. Mathis*—A brief discussion of the Darlington pulse-forming network is followed by a theoretical study of the effects of a series inductance at the input terminals and a shunt capacitance at the output terminals on the shape of the pulse produced. A group of curves with normalized parameters are presented in order to illustrate the various ways in which the rise, the peak, and the decay of a pulse for an idealized magnetron are affected.

Correspondence

A Multiport State-Space Darlington Synthesis, *B. D. O. Anderson, R. W. Brockett*

On the Existence of the A-State Matrix, *P. P. Civalleri*

Polynomial Factorization, *A. B. Macnee*

Representation Theorems for Positive Rational Functions, *I. Gerst*

A Representation for Positive-Real Operators on a Hilbert Space, *E. J. Beltrami*

Impossibility of a Class of Gyrator Realizations, *B. D. O. Anderson*

More on Ladder Synthesis of Irrational Numbers, *S. Karni*

Active *RC* Synthesis of Time-Varying and Time-Invariant State Equations, *G. O. Martens*

On Partial Fraction Expansion with Higher-Order Poles, *E. Wehrhahn*

On Interpolation in the Network Sense, *M. Soldi*

On the Unconditional Stability of Transmission-Line Networks Having Several Loads with Negative Impedance, *Y. K. Puri*

A Flow Graph Method for the Analysis of Linear Systems, *S. P. Chan, H. N. Mai*

Generation of Directed Trees and Two-Trees Without Duplication, *A. J. Paul, Jr.*

Directed Hamilton Circuits, *M. Lal*

Comment on "On the Equivalence of Resistive *n*-Port Networks," *K. Thulasiramin, V. G. K. Murti*

A Generalized Subgraph—The *k* Seg, *R. Saeks, L. M. Maxwell*

On a Problem of Diagnosis, *E. Eran, A. Lempel*

Common-Collector Impedance Transformation Sensitivity, *Q. Bilotti*

IEEE Transactions on Electromagnetic Compatibility

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Statistical Determination of Electromagnetic Compatability, *C. W. Stuckey, J. C. Toler*—A new approach to the prediction of electromagnetic compatibility between possible culprit and victim cases is introduced. It is shown that this approach, based on statistical descriptions of case emission and case susceptibility, leads directly to the determination of the probability of interference between randomly oriented equipments in operational situations. Results of tests made using a technique to describe statistically case emissions indicate that greater measurement accuracy and repeatability can be obtained with this technique than is inherent in the case-emission measurement methods currently in use. Measurements made on culprit sources in a typical laboratory work area using the statistical technique were found routinely to yield results within ±1.5 dB of corresponding values measured in a "free space" or anechoic chamber environment. When the technique was used with a hooded probe antenna, equally precise results were obtained in a shielded enclosure. Used in conjunction with appropriate statistical descriptions of case susceptibility, case-emission data such as those accumulated with the statistical technique discussed could be used to predict the probability of electromagnetic compatibility in actual equipment lash-ups.

Coupling Between Open and Shielded Wire Lines Over a Ground Plane, *R. J. Mohr*—Convenient expressions are derived, which permit accurate determination of induced interference in open (unshielded) wire and shielded wire (or coaxial) lines due to alternating and transient currents. Curves and tables are presented for obtaining key parameters in the calculation of interference. The limitations of the derived expressions are set forth and an example interference problem is solved. Experimental verification of the analysis is presented.

Shielding Circuits from EMP, *L. F. Babcock*—It is generally impractical to filter low-frequency electromagnetic pulse (EMP) signals from victim circuits. Twisting signal pair conductors is helpful but often results in insufficient isolation. The remainder must be provided by shielding. Highly permeable ferritic materials have generally been found to provide maximum shielding from low-frequency magnetic fields. It is shown that this may not be the case when the signal source is relatively distant from the shield. With large separation, there appears to be a greatly increased mismatch between the wave impedance at the shield and the intrinsic impedance of the metal. This results in much greater reflection of the impinging wave than occurs for the same signal strength with small source to shield separation. The mismatch is greatest with a highly conductive shield material. All common highly permeable materials have low relative conductivity. High permeability does not improve the shielding effectiveness at low audio frequencies because no significant attenuation occurs as the wave passes through the shield. It is concluded that materials such as copper or aluminum are logical choices for shielding circuits from distant, high-intensity, low-frequency electromagnetic pulses.

Method of Assigning the Bandwidth to a Channel, *S. A. Cohen*—It is proposed that channel bandwidth assignment be determined using the criterion that a prescribed fraction of the total radiated power of a system be contained within the channel. In order to apply this criterion to any system, its spectral distribution must be accurately known. Illustrative examples are given for this channel bandwidth computation when the output spectrum is (1) optical (Lorentzian) shape, (2) a Gaussian distribution, and (3) an AM voice signal.

Harmonic Analysis of a Half-Wave Dipole and Director Parallel to a Reflecting Plane, *J. Goldhirsh, P. P. Lombardini*—When substantial harmonic power exists at the input of a radiating antenna, a lobe structure will result that may create a substantial interference problem. In addition, the privacy of the radiating source may be severely hampered. These harmonic fields are generally dependent upon (1) the order of the harmonic relative to the geometry of the antenna, (2) the impedance the higher harmonic "sees" at the antenna input, and (3) the power available at the given harmonic. To provide a measure of the seriousness of this problem, a harmonic analysis of a particular type of antenna configuration is examined, namely, that of a center-fed, thin half-wave dipole with director parallel to a reflecting plane. The active dipole is assumed $\lambda_0/4$ away from the reflecting plane and the director $\lambda_0/8$ away from the active dipole. As a criterion to determine the worst case situation, the antenna is assumed matched at each odd harmonic examined, and equal power is assumed fed at the input. The resulting field patterns show: (1) The presence of the director results in the introduction of sidelobes at the fundamental frequency in azimuthal plane. (2) The presence of the director plays less of a role the higher the harmonic. (3) In the meridian plane the sidelobes become more intense, exceeding the forward-lobe intensity as the order of the harmonics is increased. (4) In the azimuthal plane, the sidelobe intensity is found to approach, but not exceed, the forward-lobe intensity.

Charge Time of a Linear Detector, *H. Akima*—Assuming that the ac-source impedance has a pure resistance only for the fundamental-frequency component and zero impedance elsewhere, the charging characteristics of a linear detector are analyzed, and the charge time is determined as a function of the circuit constants. Useful information on the design of a linear detector with specified charge and discharge times is given. The U.S.A. Standards Institute method for measuring the charge time of a linear detector is also studied, and an improved, simpler method is suggested.

Investigation of Choke Blinders for Feed Horns of Radar Antennas, *F. L. Cain, R. C. Johnson*—Previous studies with some reflector-type antennas have shown that wide-angle radiation, and consequently RFI, can be reduced by using "choke blinders" on the *E*-plane edges of feed horns. These choke blinders, which are arrays of choke slots or grooves, were designed such that the depth and the separation of the slots were a quarter wavelength. Subsequent efforts have been concerned with how various design parameters affect the performance of the choke blinders. Experimental studies were conducted over a wide frequency band to observe the effects of varying the number, width, spacing, and depth of the choke slots or grooves and of varying the angle, position, and length of blinders on an X-band hoghorn. The data presented in this paper enable one to make a judicious choice of the appropriate design parameters.

Comparative Radio Noise Levels of Transmission Lines, Automotive Traffic, and RF-Stabilized Arc Welders, *E. N. Skomal*—Radio interference data that have been measured throughout the frequency range of 30 Hz to 1 GHz on power transmission lines, automotive traffic, and RF-stabilized arc welders by many investigators have been assembled, converted to a common system of units, and collectively plotted. The resulting composite presentations permit an assessment of the relative interference levels produced by the three types of radio noise sources. It is concluded that below 25 MHz, lower-voltage transmission lines and RF-stabilized arc welders are the major incidental radio noise sources when the observer is within 100 feet of the source. Above 40 MHz, automotive traffic and lower-voltage transmission lines are the major radio noise sources, with neither appearing to be consistently the greater when an observer is within 50 feet or less of the source.

FABRIC, An Analysis Concept for Making Communications Systems Frequency Assignments, *H. M. Sachs*—A frequency-assignment concept based upon the use of mutual interference charts is discussed. It can be used to assign frequencies among networks of communications equipments. The model is designated FABRIC, since it develops Frequency Assignment By Reference to Interference Charts. Designed to provide a logical development of frequency assignments for any arbitrary deployment of such equipments, the model can take into account both single interference signal coupling relationships, such as spurious responses, spurious emissions, etc., and multiple interference signal effects, such as transmitter and receiver intermodulation and cross-modulation.

A Computer Expression for Predicting Shielding Effectiveness for the Low-Frequency Plane-Shield Case, *C. M. Ryan*—A computer expression for predicting the shielding effectiveness of an infinite plane shield has been developed for low frequencies (below 50 kHz). It is shown that this expression, which arises as a special case of the solution of the general wave equation, is a sum of the attenuation term of Schelkunoff's transmission theory and a remainder, which is in integral but calculable form. The computed results are in excellent agreement with values obtained experimentally for aluminum, copper, and steel. Application to cases involving highly ferromagnetic materials is hampered by difficulties in determining permeability and its dependence on frequency and field strength.

Parameter Sensitivity Analysis of an AM Voice Communication Electromagnetic Compatibility (EMC) System, *M. N. Lustgarten*—A generalized approach to EMC analysis and measurement requirements is given, considering relative parameter importance as well as the inherent uncertainties in input variables, output criteria, and consequent operational decision making. A sample problem is provided that illustrates the results obtained when three different criteria are employed.

IEEE Transactions on Electron Devices

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(Special Issue on Semiconductor Bulk-Effect and Transit-Time Devices)

Characterization of Bulk Negative-Resistance Diode Behavior, *J. A. Copeland*—Over certain ranges of frequency bulk negative-resistance diodes can act as amplifiers or as oscillators depending on the doping, length between contacts, and external circuit. This behavior can be divided into four classes: Gunn oscillation, stable amplification, LSA oscillation, and bias-circuit oscillation. These four classes of behavior are discussed generally.

Small-Signal Behavior of Gunn Diodes, *R. Holstrom*—Calculations of small-signal impedance have been made for Gunn diodes over a broad range of length and bias current density, taking into account the spatial inhomogeneity of the dc electric field. The nature of the impedance functions was found to vary with these parameters, and was distinctly different for amplifying diodes, oscillatory diodes, and diodes biased below the threshold for active behavior. Nyquist stability analysis was used to relate the impedance behavior to the effects of circuit and bias level on oscillatory and amplifying behavior. The results of this analysis are found to be in good agreement with experimental observations of other authors.

Microwave Circuit Characteristics of Bulk GaAs Oscillators, *D. C. Hanson, J. E. Rowe*—The microwave circuit characteristics of bulk GaAs transit-time mode and LSA mode oscillators have been evaluated experimentally and theoretically. Experimental measurements were performed with a waveguide-coaxial microwave circuit having two experimental degrees of freedom in which the circuit radiation impedance at the device contacts was evaluated by a dyadic Green's function method. Experiments conducted in three rectangular waveguide circuits at fixed bias voltage have established that the LSA mode frequency tuning range is determined by the magnitude and variation of the circuit series inductance X_L relative to the device low-field resistance R_o. At a bias voltage twice threshold, the tuning range is given by $1/2.4 \leq X_L/R_o \leq 2.4$. No fixed, linear equivalent circuit characterizes the LSA mode. Analysis and experimental results indicate that the device impedance of small-signal transit-time mode oscillators changes from a passive parallel *RC* impedance well below threshold to an impedance just above threshold that can be approximated by a series *RLC* circuit. The series *L* and *C* decrease linearly with transit-time mode harmonic order number.

Detailed Theory of the Negative Conductance of Bulk Negative Mobility Amplifiers, in the Limit of Zero Ion Density, *H. Kroemer*—The complex admittance behavior is calculated for a bulk negative conductivity semiconductor, such as *n*-type GaAs, in the limit of zero doping and zero trapping, when all electrons are due to space-charge-limited emissions from the cathode. Two different approximations are used: in the first, in closed analytical form, electron diffusion is neglected; in the second, by computer simulation of the internal space-charge dynamics, it is included. Both approximations agree at low frequencies where they predict a positive device conductance. Both predict a negative conductance, of slightly different magnitude, at frequencies around the reciprocal electron transit time. At higher frequencies, the diffusionless theory predicts slowly damped conductance oscillations; diffusion effects strongly increase the damping.

An Analytic Approach to the LSA Mode, *I. B. Bott, C. Hilsum*—The conditions necessary for operation in the LSA mode, and the efficiencies that can be obtained, have been calculated for a range of low-field mobilities in GaAs. The expression chosen to describe the velocity field characteristics allows direct solution of the integrals that occur in the theory and the extension of the results to include GaAs with differing values of low-field mobility. It has therefore been possible to present equations for the various parameters of interest, which are a function of low-field mobility. The results of the calculations indicate that efficiency increases with low-field mobility, but that the range of values of electron concentration frequency, becomes more restricted as the mobility is increased.

Doping Uniformity and Geometry of LSA Oscillator Diodes, *J. A. Copeland*—For maximum dc to RF power conversion efficiency, the dc and RF electric field amplitudes must be properly related throughout the volume of an LSA diode. Space charge due to a few percent fluctuation in the relative doping can distort the electric field enough to reduce the maximum attainable efficiency. Standing-wave effects with the diode limit the width in the direction of wave propagation to about 0.04 free-space wavelength.

LSA Operation of Large-Volume Bulk GaAs Samples, *W. K. Kennedy, L. F. Eastman, R. J. Gilbert*—Peak pulse powers of 350 watts with 3 percent efficiency at X-band frequencies were obtained from large-volume GaAs devices operating in the LSA mode. Experimental dependence of the LSA mode on circuit loading, applied voltage, and the ratio of carrier concentration to frequency are reported. The results are shown to be in excellent agreement with Copeland's theoretical calculations. The high-current state frequently observed in GaAs samples is shown to result from impact ionization in the high-field portion of dipole domains. A simple expression is derived relating the sample length and carrier concentration to the voltage at which switching to the high-current state occurs. The prevention of high-field domains to permit LSA operation of long samples at high voltages is briefly discussed.

Measurements of the Current-Field Strength Characteristic of n-Type Gallium Arsenide Using Various High-Power Microwave Techniques, *G. A. Acket, J. de Groot*—Determination of the current density/field strength characteristic of *n*-GaAs in the range of negative differential mobility is made difficult by field distortions and instabilities. These problems are eliminated by using microwave heating of the electrons. Various microwave techniques and the results obtained by them are described. Data on materials of various conductivities are presented. The influence of energy-relaxation and material properties are discussed.

Localized Temporary Increase in Material Conductivity Following Impact Ionization in a Gunn-Effect Domain, *J. S. Heeks, A. D. Woode*—It has been found that raising the applied bias on a long sample containing a high-field domain can result in a temporary increase in material conductivity over the region of the sample traversed by the domain while the higher bias was applied. The effect can be explained in terms of intrinsic impact ionization within the domain in the presence of a deep impurity level. The measured decay time of the "memory" is consistent with a capture cross section of about 10^{-15} cm^2, for electrons at the deep level, indicating that the empty center is neutral. Conversely, the filled center will have a high-capture cross section for holes. Following intrinsic impact ionization in the domain the mechanism is believed to involve the rapid capture of holes at the filled centers and a subsequent relatively slow return of the extra electrons to the empty centers. The deep impurity level is thus responsible for fixing the memory in position in the material and also for inhibiting the emission of recombination radiation during impact ionization.

Linear Negative Conductance Amplification with Gunn Oscillators, *H. W. Thim*—Linear microwave amplifiers with continuous power outputs of 100 mW have been constructed utilizing the frequency-independent negative conductance observed externally in Gunn oscillators. This negative conductance is exhibited only in samples containing propagating dipole layers, in other words, $n_o \cdot L$ must be larger than 10^{12} cm^{-2} for *n*-GaAs. The output power obtainable from this amplifier is substantially larger than that from a subscritically doped GaAs amplifier ($n_o \cdot L < 10^{12}$ cm^2)$^-$ because $n_o \cdot L$ can be increased. Power output and efficiency are discussed in terms of n_o and L. The upper frequency limit for amplification is determined by the time the domain takes to readjust itself after a change of external voltage, which leads to an upper limit for the $f \cdot L$ product (about 10^8 cm/s). The essential feature of the amplifier circuit is to provide both a short circuit at the Gunn oscillation frequency and a broadband circuit at the signal frequency. An average gain of 3 dB was exhibited from 5.5 GHz to 6.5 GHz. Gain compression of 1 dB occurred at 60-mW output power with 9 dB gain, and the noise figure was about 19 dB.

The Performance of X-Band Gunn Oscillators Over the Temperature Range 30°C to 120°C, *I. B. Bott, H. R. Holliday*—The output power of a cavity-controlled Gunn oscillator has been measured at a frequency of 10 GHz, as a function of bias voltage over the temperature range 30°C to 120°C. The measurements were made using 500-ns pulses to avoid significant changes in device temperature during a pulse, and at a duty cycle of 20:1 to maintain a low mean input power. The device was operated in a coaxial cavity made of Invar, and temperature control effected by operating the cavity in an oven. It has been found that there exist ranges of bias voltages over which power output and efficiency is extremely sensitive to temperature changes, and that, depending on the particular conditions, power output can either increase or decrease. The effect of increasing temperature has also been found to reduce the bias voltage required to obtain maximum power output and efficiency.

Some Properties of Gunn-Effect Oscillations in a Biconical Cavity, *G. S. Hobson*—Experiments have been performed to measure the parameters of epitaxial GaAs cavity-controlled Gunn oscillators with $nl \sim 10^{12}$ cm^{-2} over the frequency range of 7 to 20 GHz. It is found that individual devices exhibit a large variation of transit frequency with bias voltage and this is related to their performance in a cavity. The real and imaginary parts of the device reactance under cavity-controlled operating conditions and the RF voltage swing across the device have been measured. These are discussed in the light of presently available analytical theories.

The Selection of GaAs Epitaxial Layers for CW X-Band Gunn Diodes, *C. Hilsum, J. R. Morgan*—Results are reported on 1000 diodes made from about 50 GaAs epitaxial layers. The layers are classified for quality according to the power output of the average device, and the correlation between quality and epitaxial layer thickness l and resistivity ρ examined. It is shown that the quality cannot be linked to the thickness or resistivity alone, but is closely connected with the ratio of thickness to resistivity. Ninety-five percent of all slices with $4.5 < l/\rho < 10$ yield good results. It is shown that this is in good agreement with theory.

Gunn Effect in CdTe, *G. W. Lidwig*—The response of *n*-type CdTe to pulsed electric fields has been examined. In the best units prepared to have a uniform cross section, the current remains ohmic to good approximation—almost to threshold. Above the threshold field of (13 ± 2) kV/cm, well-defined Gunn oscillations are observed with a spike amplitude 35 to 50 percent of the total current. A domain drift velocity $v_d = 7 \times 10^6$ cm/s, a field outside the domain $E_1 = 7$ kV/cm, and a domain field $E_2 \gtrsim 37$ kV/cm is estimated. After a few nanoseconds of operation, however, current runaway occurs in units showing the spiking mode of oscillation, presumably because of carrier ionization induced by the moving high-field domains.

Contribution to the Experimental Study of the Gunn Effect in Long GaAs Samples, *P. Guétin*—Some experimentally observed features of the Gunn effect in long samples (0.1 to 0.4 cm) of GaAs with a resistivity of 1 to 4 Ω-cm at room temperature are described. The normal behavior of current oscillations and the effect of inhomogeneities may be qualitatively well understood if the characteristic of the excess voltage in the high-field domain versus the electric field outside it are taken into account. Thus it is shown that when a domain moves through a sample with doping inhomogeneities, its velocity remains almost constant at every point inside the specimen whereas the current fluctuation is rather large from one region to another. Fields in excess of 130 kV/cm were found to exist in domains that always present a triangular shape. Changing the starting point of a domain has been easily achieved by putting a grounded coil along the side of a long sample. The following new pheneomena are reported: (1) Transient changes take place in material conductivity in normal conditions of operation and also when a sample containing a high-field domain is subjected to an additional negative voltage spike. (2) Recombination radiation occurs in specimens with a resistivity of 1 to 4 Ω-cm operated in the trigger mode. This emission is associated with a switching of the current and correspondingly the domain takes a new configuration in which the maximum field is only 25 kV/cm or less. (3) Migration of tin occurs due to the effect of the high-field domain. At each domain transit, the length of migration is about 4 Å.

Generalized Small-Signal Analysis of Avalanche Transit-Time Diodes, *B. Hoefflinger*—The one-dimensional small-signal analysis of avalanche transit-time diodes with distributed multiplication is reduced to the concept of two layers in cascade, each having a constant ionization rate. The interface is located in the distinguished neutral plane of equal dc electron and hole currents. In this configuration, the small-signal problem is characterized by two parameters; namely, the location of the neutral plane in the depletion layer and a quantity combining the ionization-rate field dependence and the total direct-current density. Normalized admittance diagrams and small-signal growth rates are given that show the relative importance of the low-transit-angle mode where the frequency is smaller than the avalanche resonance frequency and the π mode extending almost to 2π for large current densities. Through a transformation, the results are applicable to Read-type, abrupt, and uniform junctions of Si, Ge, and GaAs avalanche diodes.

A Small-Signal Theory of Avalanche Noise in IMPATT Diodes, *H. K. Gummel, J. L. Blue*—A general small-signal theory of the avalanche noise in IMPATT diodes is presented. The theory is applicable to structures of arbitrary doping profile and uses realistic ($\alpha \neq \beta$ in Si) ionization coefficients. The theory accounts in a self-consistent manner for space-charge feedback effects in the avalanche and drift regions. Two single diffused n-p diodes of identical doping profile, one of germanium and the other of silicon, are analyzed in detail. For description of the noise of the diodes as small-signal amplifiers the noise measure M is used. Values for M of 20 dB are obtained in germanium from effects in the depletion region only, i.e., when parasitic end region resistance is neglected. Inclusion of an assumed parasitic end resistance of one ohm for a diode of area 10^{-4} cm^2 produces the following noise measure at an input power of 5×10^4 W/cm^2, and at optimum frequency: germanium, 25 dB; silicon, 31 dB. For comparison, a noise figure of 30 dB has been reported for a germanium structure of the same doping profile as used in the calculations. Measurements of silicon diodes of the same doping profile are not available, but silicon diodes typically give 6 to 8 dB higher noise figures than germanium diodes of comparable doping profile.

Microwave Si Avalanche Diode with Nearly-Abrupt-Type Junction, *T. Misawa*—Microwave Si avalanche diodes with a nearly-abrupt-type junction have been made. The maximum output power so far obtained in CW operation is 1.1 watts at 12 GHz with an efficiency of 7.7 percent. The maximum efficiency observed is 8.0 percent. The improved performance over the previously reported pνn structure, for which the best result was 250 mW at 12 GHz with an efficiency of 2.8 percent, results from a reduction in length of the avalanche region in the abrupt junction. In the previously reported pνn diode the efficiency is still sharply increasing at the burnout point, whereas in the present diode the efficiency is nearly saturated at the burnout point. The advantages and disadvantages of using different polarity of the diode (p on n or n on p) and different material (Ge) are given. Small-signal theory was used to analyze device operation.

Composite Avalanche Diode Structures for Increased Power Capability, *C. B. Swan, T. Misawa, L. P. Marinaccio*—The possibility of operating several avalanche oscillator wafers in parallel to obtain higher power and/or higher efficiency CW operation is explored analytically and experimentally. Experiments show that over a wide range the efficiency is roughly proportional to the power density in the semiconductor. The power densities required for good efficiency are very high and cannot be achieved in large-area junctions without an excessive temperature rise caused by the thermal spreading resistance of the heat-sink material.The scheme delineated considers small-area wafers spaced sufficiently close electrically that they operate as a single avalanche oscillator whereas their physical separation permits essentially independent heat sinking. It has been found that, as expected, the efficiency for CW operation improves approximately inversely with the diode diameter whereas the power capability for a given size of wafer increases directly with the number of such wafers employed. The relative merits of mounting diodes on copper and on diamond are discussed. Experimental work indicates that the present approach is capable of producing 10 to 15 watts CW at 14 GHz in a single oscillator with available silicon diodes.

Two Types of Microwave Emission from InSb, *H. Morisaki, Y. Inuishi*—Two types of microwave emission from InSb plasma subjected in the crossed electric and magnetic fields were investigated experimentally. From the simultaneous measurements of Hall effect and microwave emission, the threshold condition of the one type of emission was obtained as $(\omega_c \tau_r)^2 \cdot \Delta n \gtrsim 3 \times 10^{14}$ cm^{-3}, where ω_c, τ_r and Δn are electron cyclotron frequency, relaxation time, and electron-hole pair density, respectively. It was also found that the Hall mobility showed anomalous decrease above the threshold. The emission power of the other type of emission shows maximum value at several values of the applied magnetic field lower than the threshold of the noise-type emission. These characteristic magnetic fields were not influenced by current density except for a slight change in the low-current-density region.

Microwave Instability in n-Type Indium Antimonide, *G. Bekefi, A. Bers, S. R. J. Brueck*—Indium antimonide emits microwave noise when it is subjected simultaneously to parallel dc electric and magnetic fields whose values exceed certain thresholds. Comparison of the emission characteristics at 77°K with those at 4.2°K shows two major differences: (1) The threshold magnetic field at 4.2°K is approximately half that at 77°K. (2) With increasing magnetic field the emission at 4.2°K is comprised of a background continuum upon which are superposed equally spaced resonant spikes. At 77°K, the background continuum only is observed. A theoretical model for the threshold characteristics is presented based on the assumption that the observed instability arises from phonon excitation by the drifting electrons.

Cyclotron Waves in InSb, *J. M. V. Nieuwland, M. T. Vlaardingerbroek*—The propagation of cyclotron waves through InSb is studied. The frequency used was 140 GHz (λ = 2.14 mm) and the dc magnetic field strength was between 0 and 10 kG. Theory and experiments are in reasonable agreement.

Current Oscillations in CdS Caused by Acoustoelectric Domain Motion, *A. Ishida, Y. Inuishi*—Current oscillations caused by acoustoelectric domain motion were investigated in semiconducting and photoconducting CdS at room temperature. Oscillatory behaviors of the current are closely connected with the domain motion. Four different behaviors of the domain were observed in several samples. In the homogeneous semiconducting CdS, the domain is built up through local amplification of thermal phonons due to spatial fluctuations of phonon density distribution. Its "formation site" depends upon the applied electric field. In the inhomogeneous ones, the domain is usually formed at the region of electric-field concentration. In the homogeneous photoconducting CdS, damped oscillations of the current were observed. The domain formation may be attributed to amplification of acoustic shock wave generated at the cathode. In the inhomogeneous ones with a high-resistivity region near the anode, the domain is formed at the high-resistivity region and it seems to be dragged by some acoustic stimulations such as shock-excited acoustic waves. Formation time of the domain was also investigated in the homogeneous semiconducting CdS. Conductivity dependence of it seems to support the quantum theory but exclude the White's formulation.

Field-Effect Transistor (FET) Bibliography, *H. F. Storm*—This list of references contains over 200 entries, but no claims are made as to its completeness. The references for the era 1939 through 1963 refer to field-effect transistors, in general, and were obtained mostly from J. T. Wallmark's article "The Field-Effect Transistor—an Old Device with New Promise" (IEEE SPECTRUM, pp. 182–191, Mar. 1964). The subsequent references (1964 to mid-1967) relate predominantly to insulated-gate field-effect transistors, designated in the literature as IG-FETs. Often, more specific terms are used: for a structure consisting of a metal gate, insulating layer, and semiconductor substrate, the term MIS-FET appeared in the literature. If the insulating layer is an oxide, the terms MOS-FET or MOST are widely used. If the IG-FETs are fabricated by the so-called "thin-film" process, then they are called thin-film transistors, and are designated in the literature by TFTs; however, not all TFTs are FETs.

Correspondence

Gunn Oscillator with One Electrode Split, *A. Nordbotten*
Injection Priming of Pulsed Gunn Oscillator, *B. G. Bosch, H. Pollmann*
Generation of Subnanosecond Pulses with Bulk GaAs, *R. E. Fisher*
High Peak Power Epitaxial GaAs Oscillators, *B. E. Berson, Y. Narayan*
Electrical Performances of GaAs Epitaxial Gunn-Effect Oscillators, *H. Murikami, K. Sekido, K. Ayaki*
Two-Port Microwave Amplification in Long Samples of GaAs, *P. N. Robson, G. S. Kino, B. Fay*
Design of Gunn Devices for CW Operation, *R. Becker, B. G. Bosch*
The Gunn Effect in *n*-CdTe, *M. R. Oliver, A. G. Foyt*
Failure Modes in Silicon Avalanche Transit-Time Microwave Devices, *J. F. Schneck, T. A. Midford*
Effects of Uniaxial Stress on Silicon Avalanche Transit-Time Oscillators, *T. A. Midford, H. C. Bowers*

IEEE Transactions on Engineering Management

Vol. EM-14, no. 3, September 1967

Dynamics of R&D Activity, *J. R. Schnittger*—A conceptual analysis is presented which is a method of reducing the fundamental technology of any company. Venn diagrams and matrix formulation are used to apply the technology of the company in diversified areas. The simplest entropy concept of information theory is employed to describe the management of a development program; selection of the portfolio is included. A unique queuing model is employed that yields the influence of the "load" and the R&D organization on the number of projects satisfactorily completed during a budget period.

Experience as a Factor in the Selection and Performance of Project Managers, *I. M. Rubin, W. Seelig*—The study reported focuses first on the relationship between a project manager's background characteristics and certain characteristics of the projects he is asked to manage. The impact of this decision process is then examined by relating project manager experience and project characteristics to measures of project performance. The findings indicate that organizations select their oldest and most experienced project managers to direct large, high-priority projects. Performance is then superior without relation to the project manager's total experience, but in relation to the high priority given larger projects. With the exception of a measure of "growth in responsibility," none of the measures of the project manager's experience were found to bear any direct relationship to project performance.

The Relationship Between Interstate Variations in the Growth of R&D and Economic Activity, *I. Horowitz*—The relationship between regional R&D growth and subsequent regional economic growth is analyzed empirically. The rates of growth from 1920 to 1964 are calculated for various economic variables and R&D in the 48 contiguous states. The correlation coefficients of the growth equations measure consistency in growth. These coefficients are then analyzed via a correlation procedure. The results suggest that regions enjoying the most consistent rates of growth in R&D activity will subsequently enjoy, if not the most rapid economic growth, the smoothest and most consistent pattern of future economic growth.

The Present Value Criterion in Military Investments, *V. L. Broussalian*—Since the benefits of a military investment are not marketable, the investment itself is also not marketable. It follows that there is no way in which the cost profile of such an investment can even conceptually be varied, except by government borrowing or by adoption of an alternative investment. Hence, in the absence of borrowing, a cost stream represents a unique profile of resource withdrawal from the private sector of the economy. Yet the computing of a present value of such a cost stream would imply that it is exchangeable, at least in principle, with all streams that have the same present value of two specific cost streams (of two military investments) and cannot be a proxy for the comparison between the two profiles of resource withdrawal which the cost streams represent. It is pointed out that government can resort to public borrowing to change the profile of taxes necessary to pay for the investment, and thus, to some extent, change the profile of real resource withdrawal from the private sector. If the borrowing and taxing operations could result in predictable real resource withdrawals, then a present value criterion, using the borrowing rate as the discount rate, could be formulated: Of two cost streams, the one with the lesser present value would permit resource withdrawals that dominate those that the other would permit. Unfortunately, the state of the art has not advanced to the stage where such predictions could be made with any degree of confidence.

Management Engineering and Forecasting, *P. A. Clavier*—An important feature of dealing with overall management problems is the fact that the economic behavior of a company is averaged over a fixed quantum of time, i.e., one year. Because economic variables are yearly averages, the economic world is endowed with a periodic substrate. The economic world is a sort of crystal, and economic variables behave much in the manner of physical entities in crystals.

The Need for an Organized Approach to EMI (Electromagnetic Interference) Control, *R. D. Goldblum*—Electromagnetic interference control refers to the ever-increasing problem of controlling the adverse effects of EMI on electronic equipment. Atmospheric noise due to the phenomena of solar radiation and the ionosphere is one form of ambient interference, but man-made noise adds to the ambient solar interference and increases the ambient intensity by many orders of magnitude. Descriptions are given of several undesirable effects of man-made interference. The interference problem is discussed, as well as many reasons for concern. An approach to EMI control is suggested, including the outline of a proved EMI control program.

IEEE Transactions on Human Factors in Electronics

Vol. HFE-8, no. 3, September 1967

Spelled Speech as an Output for Computers and Reading Machines for the Blind, *K. R. Ingham*—The development of a speech display system for the blind built around the TX-0 and PDP-1 computers at the Massachusetts Institute of Technology is described. The system, dubbed "SPANC," was designed to permit the application of a variety of sound-compression techniques to be used. Spelled-speech alphabets and displays were developed. An investigation of the letter sounds was carried out for the purpose of revealing the positions where cuts could be made so as to achieve high reading rates yet retain smooth coalescence. Identification of the positions of these cuts could be made with gross features of the acoustic waveform. Cuts of more than 50-ms duration could be made in the region of the articulatory transitions for the consonants, and very acceptable representations of the letter sounds could be obtained by preserving this region for the vowels. Finally, the overlapping of letter utterances as a compression technique was accomplished with subjects experiencing very little difficulty for overlaps corresponding to reading rates of 90 and 120 words per minute.

Internal Models and the Human Instrument Monitor, *R. D. Smallwood*—A general structure for the quantitative modeling of human operator behavior is discussed. The primary features of this structure are (1) the mathematical description of the updating of operator information state by an internal model of the environment and (2) the assumption of optimal behavior on the basis of current state of information. An application to simple instrument monitoring is presented. A first- and second-order internal model are studied and the second-order internal model is shown to predict human sampling behavior that is more consistent with the experimental data.

An Experimental Study of Human Operator Models and Closed-Loop Analysis Methods for High-Speed Automobile Driving, *W. W. Wierwille, G. A. Gagné, J. R. Knight*—The investigation described was aimed at obtaining information about the way in which the human being controls an automobile at high speed on a winding road. A dynamic systems approach was taken, and three different classes of models were postulated. The optimal models in these classes were then obtained for data taken from three subjects in a driving simulation that projected a large moving roadway image. The three subjects were chosen in such a way as to make possible (1) a comparison of driving behavior and compensatory tracking behavior of subjects with similar backgrounds, and (2) a comparison of driving behavior of a male subject with technical training and driving behavior of a female subject without technical training. This behavior was quantitatively defined by synthesizing optimal models from the experimental data, using the digital computer. The models were then used to perform closed-loop man–machine system servo analyses of the automobile driving tasks and the corresponding tracking tasks. It is clearly demonstrated that, under idealized conditions, standard control system techniques may be extended to make possible the quantitative study of the control of an automobile at high speed by a human operator.

Two-Dimensional Manual Control Systems with Separated Displays, *W. H. Levison, J. I. Elkind*—The results of a current study of multivariable manual control systems are presented. The objectives of this study are to investigate the human controller's behavior in multivariable control situations and to develop models of the controller that take into account both the monitoring and the control functions that he typically performs in such systems. A series of two-variable manual tracking experiments was performed in which subjects were required to view two separated displays and operate two control devices to control the system. Performance was measured as a function of the display separation, the forcing function bandwidth, the task difficulty, and the controlled-element dynamics. Human controller describing functions, eye movement distributions, and normalized mean-squared tracking error were obtained. Measurements of human controller describing functions when a single display is viewed peripherally for control of a single-variable system were also obtained. A model for the human controller in the two-axis control situation was developed. It was tested against the data and was found to be a good predictor of performance. Extensions of this model to higher-dimension systems are discussed.

Human Performance in a Cross-Coupled Tracking System, *E. P. Todosiev*—Human tracking performance in a two-axis system with cross-coupling was evaluated by modeling the human operator with an asymmetric lattice network. A spectral analysis technique was developed precisely to identify each element of the network. Approximate identification is possible by using a less complex model-matching technique. Four compensatory tracking system configurations with various degrees of symmetrical and asymmetrical cross-coupling were investigated. Decoupling equations were analytically derived that permit prediction of the cross-coupling elements in the lattice model in terms of the uncoupled elements and the plant dynamics. Analysis of a tracking experiment indicated that a trained human operator could essentially uncouple a coupled two-axis system with second-order plant dynamics, provided the coupling was such that the operator was not required to introduce a 180-degree phase shift in generating the decoupling signal.

The Adaptive Response of the Human Controller to Sudden Changes in Controlled Process Dynamics, *D. C. Miller, J. I. Elkind*—A model is presented for the process by which a trained human controller detects, identifies, and adapts to changes in the gain and polarity of a compensatory velocity control system. The results of some experiments designed to test the model against actual human behavior are described. The features of the model that are explicitly tested are: (1) a detection process in which contemporary signal detection theory is applied to a variable that represents the difference between observed and expected system response to control movements; and (2) an identification process in which the human controller chooses that member of an ensemble of mental models of the controlled process that best accounts for the observed system behavior. Other features of the model that were not explicitly tested but that appear reasonable are: a modification process in which the human controller very rapidly adjusts his tracking behavior to suit the new model that he has chosen, and an optimization or "fine-tuning" process in which he adjusts his behavior to minimize his tracking error.

Muscle Action Potential and Hand-Switch Disjunctive Reaction Times to Visual, Auditory, and Combined Visual–Auditory Displays, *M. J. Wargo, C. R. Kelley, D. J. Prosin, M. B. Mitchell*—Muscle action potential and hand-switch disjunctive reaction times of three male subjects to visual, auditory, and combined visual–auditory display were observed. Muscle action potential responses were found to be considerably faster than hand-switch responses. Within each response mode, reaction times with the combined display were faster than visual display reaction times.

Rotary Dial and Thumbwheel Devices for Manually Entering Sequential Data, *R. L. Deininger*—A rotary telephone dial and a device consisting of ten thumbwheel switches in a single array were compared in terms of user speed, accuracy, and preference. Where a completely different telephone number was used during each trial, the thumbwheel device took 20 to 60 percent longer than the rotary dial and was disliked by nine out of ten subjects. In contrast, where the successive trials involved telephone numbers with the same prefix, the thumbwheel device took 40 to 60 percent less time than the rotary dial and was preferred by eight out of ten subjects. Error rates were low and the same on both devices.

A Review of Quasi-Linear Pilot Models, *D. T. McRuer, H. R. Jex*—During the past several years, an analytical theory of manual control of vehicles has been in development and has emerged as a useful engineering tool for the explanation of past test results and prediction of new phenomena. An essential feature of this theory is the use of quasi-linear analytical models for the human pilot wherein the models' form and parameters are adapted to the task variables involved in the particular pilot-vehicle situation. The current state of these models is summarized, including background on the nature of the models; experimental data and equations of describing function models for compensatory, pursuit, periodic, and multiloop control situations; the effects of task variables on some of the model parameters; some data on "remnant"; and the relationship of handling qualities ratings to the model parameters.

Communications

A Laboratory Display System Suitable for Man–Machine Research, *W. W. Wierwille, G. A. Gagné, J. R. Knight*

Motor Unit Myoelectric Control, *A. Stein, D. H. Lewis*

IEEE Transactions on Industry and General Applications

Vol. IGA-3, no. 4, July/August 1967

European Developments in Resistance Welding, *W. E. Masing*—The United States has played and still plays the leading role in the development of the resistance welding technique. Spot welding of both structural steel in heavy construction and light alloys are mentioned in the early thirties. The first mercury-rectifier controlled resistance welding machine was shown in Europe about the same time. Control techniques have developed along the same lines as in the United States. Some unusual techniques of nondestructive testing, presently being developed in Europe, are outlined. Details of a flash-butt welding machine are given. The cooperation of welding societies and research bodies within Europe and the European contribution to the International Institute of Welding are explained.

Dynamic Evolution of Events Accompanying the Low-Voltage Discharges Employed in EDM, *T. O. Hockenberry, E. M. Williams*—Experimental studies of the evolution of events accompanying a transient, low-voltage sparkover-initiated discharge between closely spaced electrodes in a liquid dielectric are described. The discharge parameters and the electrode configuration are similar to those found in electrical discharge machining (EDM) applications. High-speed photomicrographic records of the dynamic evolution of the discharge column and the gas bubble created by the discharge are presented. Additional photographic evidence of the details of electrode metal erosion dynamics is given. The photomicrographs suggest that metal erosion takes place at the beginning of the discharge current pulse and after the termination of the discharge current pulse.

Secondary Feedback in On–Off Electric Heating Processes, *W. K. Roots, F. Walker*—Secondary feedback is used in the on–off control of electric heating to reduce the cycling time, but usually the secondary feedback loop is incorrectly designed and the droop error results. New concepts and techniques are introduced for analyzing the dynamics of a secondary feedback loop, and new design criteria are derived whereby the benefits of secondary feedback can be obtained without incurring the droop penalty.

A Temperature Control and Electric Heating Bibliography, *W. K. Roots, F. Walker*—This bibliography of more than 200 references has been selected to provide a background for research and development activities in temperature control and electric heating. In the first section of this bibliography the references are listed in the numerical order in which they relate to the paper "Secondary Feedback in On–Off Electric Heating." In the second part they are indexed under the salient subject headings.

The Need for Group B Equipment, *R. Loewe, R. Scott*—It is pointed out that the increased usage of hydrogen in the nuclear and aerospace industries has multiplied the need for suitable electric equipment for Group B applications, both for Division 1 and 2 of Class I. Although there is almost a complete line of items on the approved lists for Group D, almost nothing is found in comparison for Group B. By approved lists is meant that of Underwriters Laboratories, Inc., Canadian Standards Association, and Factory Mutual. Users such as Argonne, not being subject to the stringent rules of local inspection authorities, can use what are often called "approvable" items—items that, on the basis of manufacturer's tests, are believed to be approvable if submitted to Underwriters, etc. The National Electrical Code (NEC) provides egal definitions for Class, Division, and Group. The Recommended Practice RP500A of the American Petroleum Institute provides help for refinery and similar classification problems. The three means available for use in hazardous area work are explosion-proofing, intrinsic safety, and purging and pressurization. The existing lists of approved items show such things as fittings, receptacles, lights, starters, switches, flexible connectors, telephones, and loudspeakers. The so-called approvable items include panelboards, ground detectors, valves, pressure switches, and a limited number of other items. Some of the pioneering work has been done in European laboratories, especially in the field of intrinsic safety. Among items developed in Europe, but not in the United States, are motors for hydrogen service. Among the items that could be developed in the United States are drains, breathers, portable lights and flashlights, motors, large starters and contactors, and many items of control and instrumentation.

Industrial Torque Measurements Using Magnetostrictive Torquemeters, *T. H. Barton, L. Solar*—A magnetostrictive torque transducer comprises a length, of the order of six inches, of solid or hollow shaft of ferromagnetic material equipped with magnetization and signal pickup windings. A variety of stationary and rotating coil systems can be employed, but all are characterized by a mutually perpendicular arrangement of the magnetization and pickup coils so that no voltage is induced in the latter by the alternating magnetizing current at no load. Torque diverts some of the flux to the pickup coils, the EMF thereby produced being a measure of the torque. A correctly designed transducer has a linear transfer characteristic and is capable of directly operating a robust meter. It is insensitive to fluctuations in supply voltage and, because it normally operates at low stress levels, the shaft portion is of great stiffness and has high overload capacity. If a small speed dependence can be tolerated, both exciting and pickup coils can be stationary. For the highest accuracy, of the order of ±0.2 percent, the exciting coil must rotate with the shaft.

Mode-Dependent Time Constants in Electric Space Heating Processes, *W. K. Roots, J. T. Woods, F. M. Wells, R. H. Tull*—Adequate comfort conditions in any space-heating process can be assured only if a good understanding of the dynamic temperature variations is possessed. The vast majority of published literature considering the system dynamics assumes that the temperature variations have an exponential increase or decrease with time, and hence that the thermal system can be modeled by linear RC equivalent circuits. These linear models have a severe restriction in that the time constant of the exponential variations remains constant under all conditions. A few published articles giving experimental data have indicated that in discontinuously controlled electric heating processes the system time constant during heating (active time constant) is not necessarily the same as the system time constant during the interval in which no heat is supplied (passive time constant). Experimental data, taken under rigidly controlled conditions, are presented that conclusively show that the active and passive time constants of a typical residential structure using electric heating are not necessarily equal. An analytical model which accounts for the difference in these time constants is introduced, and the time constants are presented in terms of the model parameters. Finally, the method for measuring the system time constants is outlined, and a simplified graphical method of extracting all system parameters necessary for an analysis of the system dynamics under control is derived. These tests showed that in a single-disturbance environment chamber, of the type commonly used to test space heating systems, the time constant increases from 15 to 20 percent, measured at typical occupant locations, as the process changes from its active to its passive mode. Previously published analytic techniques should be modified to cater for the mode variance of the process time constant.

Interferometers for Use as Integral Parts of Machine Tools, *R. Schede*—A simple, compact laser interferometer has been developed for use as a length-measuring transducer on various types of machine tools. The size, which is less than a two-inch cube, and rugged construction, with all optical components glued or otherwise rigidly secured, make mounting on machine tools an inexpensive operation; and the units do not interfere with normal machine operation. The design requirements of interferometers for these applications are discussed with the specific critical design features of this unit. This includes electronic as well as optical design. These interferometers have been used on both manually operated machines and automatic numerically controlled units where the interferometers act as the feedback elements. Inspection machines with their higher accuracy requirements have received most of the installations, but fabrication machine installations have also been made. The operating experience, which extends over a year on some installations, is discussed in relation to present-day limitations and drawbacks. Photographs of installations with the interferometer and the actual interferometer package are shown.

Electrified Railroad Supply from Utility Transmission Systems, *W. S. Einwechter, B. A. Ross*—Problems are examined that are associated with utility supply to single-phase, 60-Hz railway loads from the three-phase utility transmission system. Supply techniques and limitations are recommended that will insure satisfactory operating conditions from both utility and railroad standpoints. Service aspects considered include: reliability and supply station facilities, phase and voltage unbalance effects, anticipated power factor, harmonics, radio, and inductive interference. There appear to be no insurmountable problems associated with supplying foreseeable railway loads from utility high-voltage transmission systems and no requirement for railroad transmission facilities or special balancing equipment exists.

Design Data for a Multiple-Output DC Regulator System, *R. E. Weber, E. S. McVey*—The analysis of a new multiple-output dc regulating system is presented. Regulation is achieved by switching between two ac levels in the primary of the power transformer. One output is precisely regulated because it is used for control purposes. The other outputs are essentially independent of line voltage, but do have regulation associated with the voltage drops in their filter inductors and rectifiers. Equations needed for design are plotted in a normalized manner. Load current must not become less than the critical current required by the filter inductor if regulation is to be maintained. A design example illustrates the use of the information presented earlier in the paper. Basic circuit concepts are included.

Specialized Apparatus for Testing Subway Cars, *F. W. Roberts*—Methods of making tests of a varied nature on subway cars are described and details of pieces of apparatus are given. Instrumentation for recording braking tests is discussed and followed by discussion of rapid distance recording. A novel form of speedometer is detailed and its special drive mechanism is described. A brief comment on accelerometers is followed by opinions on the criteria for desirable current–voltage recorders. The need for time synchronization of paper charts and a method of providing every recorder simultaneously with an accurate common time scale trace is described. Comments on common temperature measurements and a description of a little-known method of high-temperature recording follow. A simple duty-cycle meter and a device for detecting partial breaks in cables are discussed, followed by a synopsis of a few other devices used in Toronto.

IEEE Transactions on Instrumentation and Measurement

Vol. IM-16, no. 3, September 1967

A Two-Space Fluid Mapper, *W. E. Rogers, G. A. Pfaff*—A fluid mapper has been constructed whose boundaries act as though they were infinite in extent. This effect is achieved by using two interconnected flow spaces. An application of the device is illustrated, and the accuracy is evaluated by means of a proposed quality factor.

An Unusually Accurate Universal Potentiometer for the Range from One Nanovolt to Ten Volts, *L. Julie*—Recent interest in accurate dc measurements down to nanovolt levels has prompted the development of a wide-voltage-range potentiometer of a new type with seven-dial resolution and extremely high accuracy. The design is almost perfectly "neutral." All switch contacts and resistors of the main potentiometer operate at high-voltage levels, and contribute thermal EMFs that are attenuated by a factor of 10 000 times (to less than 0.1-nV levels) on the nanovolt range. The device serves as an "autocertified" voltage potentiometer standard. It is certified traceable to NBS units using previously published "ratiometric" techniques, and is capable of direct reading accuracy without correction from 2 ppm on the 10-volt range to 10 ppm of setting ±1 nV on the 0.001-volt range. The Thévenin equivalent source resistance of the instrument is approximately 2.5 ohms on the 0.001-volt range, reducing Johnson noise levels to less than 1 nV with practical null detector smoothing times. The instrument is designed so that it can be used both as a potentiometer and as a seven-dial Kelvin–Varley divider. The control portion of the instrument is separately packaged and can convert dividers now in use to this new type of universal potentiometer standard. A complete theoretical study of the design characteristics of this state-of-the-art potentiometer is included, as well as an analysis of all sources of error in the completed instrument. Experimental data, obtained by a step-ratio process, are presented in confirmation of the theoretical predictions of accuracy, and calibration data obtained from this method are shown extended down to the nanovolt level.

Thermistor Bead Matching for Temperature-Compensated RF Power Thermistor Mounts, *E. Aslan*—The temperature-compensated thermistor power meter of the dual-bridge design for many years has been the most widely used instrument for microwave power measurement. During these years little has been written on the manner or criteria for matching the thermistor beads. An attempt is made to fill that void. The procedure for matching thermistor beads for less than 2 $\mu W/^\circ C$ drift is to be accomplished by pairing the dR/dt characteristic of each bead and adjusting the dP/dR characteristic for a match. dR/dt of the beads may be determined from resistance data at 90°C and 110°C, and the expression

$$dR/dt = 9.4497[\ln R_a - 1.11648 \ln R_b + 0.61749]$$

which is derived for 200-ohm operating resistance thermistors. The thermistor beads are then paired by selecting such that dR_1/dt and dR_2/dt are within one percent of each other. The conditions necessary for matched dP/dR of the thermistor beads are developed and procedures indicated. The paired beads are installed in the thermistor mount and the constant dP/dR of each bead adjusted for equality by moving the heat sink of one of the thermistors until a balance is obtained.

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GENERAL DYNAMICS

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The Measurement of Effective Resolution of Non-Wire-Wound Potentiometers, *A. S. Williams*—The measurement of the effective resolution of non-wire-wound potentiometers has been simplified by the development of test equipment that makes use of the "resolution window" concept. This concept is briefly described, and two methods of mechanization are considered. Analytical and practical experience has shown that the sampling method is the most promising to date, and the development of equipment using this approach is therefore discussed in detail. The concept of the "detection aperture" is introduced, and its use in predicting the effective sampling coverage is shown. As a result of these developments, a definite number can now be ascribed to a given non-wire-wound potentiometer to describe its resolution capability. It is anticipated that the introduction of these ideas for resolution measurement will contribute materially to the establishment of resolution standards for non-wire-wound potentiometers.

A Thin-Film Bolometer Unit, *K. Sakurai, T. Nemoto*—The bolometer unit widely used for measuring microwave and millimeter-wave power becomes more difficult to construct and obtain good performance, as the wavelength gets shorter. To overcome these difficulties, a new unit has been developed that has a very simple structure by virtue of a new matching procedure. The bolometer element is made of a thin metal film evaporated on a thin mica substrate, and its mount consists only of a short circuit. Experimental units have been designed at 35 GHz and 10 GHz, and these have demonstrated excellent characteristics, such as high efficiency, low VSWR, wide bandwidth, and high power-handing capacity. The thermistor units applying the same matching theory are also investigated at 35 GHz and 50 GHz.

A Laser Microcalorimeter, *K. Sakurai, Y. Mitsuhashi, T. Honda*—A new type of microcalorimeter as a laser power standard in Japan has been developed at the Electrotechnical Laboratory. This is a double calorimeter in which the laser power is measured by a dc substitution method using a thermopile unit, and simultaneous measurement is also made using the Peltier cooling-type calorimeter by dc substitution. The CW power of the gas laser (He-Ne) is controlled with high stability (± 0.05 percent) by the automatic power control system using the Faraday-rotation component. By this method and equipment, the "effective efficiency" of the standard thermopile unit is determined precisely. The errors in this microcalorimetric technique are investigated with the aid of a heat flow analysis and auxiliary experiments. As a result the absolute accuracy of the CW power measurement of laser beams (6328 Å, 1.15 μm) is evaluated with high accuracy better than 0.5 percent. The experiments have been successful at 6328 Å and 1.15 μm, and this method is considered to be available at the region of infrared and far-infrared wavelengths.

An Accurate, Semiautomatic Technique of Measuring High Resistances, *S. H. Tsao*—An accurate, semiautomatic method of calibrating high-resistance standards is described. Measurements of resistances between 10^9 and 10^{14} ohms at a minimum of 1 volt or 10^{-12} ampere can be made with an accuracy better than 0.1 percent, each determination requiring typically from 0.5 to 50 seconds. The value of resistance is determined in terms of a fixed three-terminal capacitance, a resistance ratio, and a standard frequency, all being stable and accurately determinable quantities. The sources of errors and their minimization are discussed; the construction and operation of such a device are described.

Analysis of Rotationally Misaligned Stators in the Rotary-Vane Attenuator, *W. Larson*—Two types of error are caused by misaligned stators in the rotary-vane attenuator. For each type the actual attenuation will differ from the indicated attenuation values throughout most of the usable range of the attenuator. This analysis illustrates that these two types of error are related to the technique of alignment used in establishing the zero reference of the rotating vane to the stator vanes. Equations pertaining to these errors are discussed, and are solved with the aid of tables of attenuation error as a function of vane angle error for rotary-vane attenuators. Graphs of both types of error are presented determining the parameters needed to establish limits of machining tolerances for each waveguide size.

Calibration of Thermal Transfer Standards of RF Voltage, *R. F. Clark, A. Jurkus*—A system of RF voltage calibration in the VHF and UHF ranges is described. The primary standard is a calorimetric power meter whose impedance is determined accurately. The working standards are thermal transfer instruments (thermal converters and micropotentiometers). The methods used to calibrate the working standards against the primary standard are described in detail. Then the calibration of transfer standards submitted by other laboratories is outlined, and procedures and practices that have been found to be successful in the past are recommended for use by standardizing laboratories.

Study of an Analog Computer System for Reconstruction of Three-Dimensional Figures from Planar Projections, *E. Hirsch*—An electronic analog computer remapper (reconstructing, mapping, and projecting analog computer) is studied, capable of reconstructing figures, graphs, shapes, etc., in three- or higher-dimensional spaces from their two-dimensional projections given in the form of drawings, slides, or photographs. The pattern of the reconstructed figure can then be distorted, remapped according to certain transformations, reprojected on desired planes to form new, differently parallaxed pictures of the reconstructed figure, or simply stored in a digital computer memory as a list of coordinates or vector components of points in space, together with their corresponding brightness values.

Conductivity Measurements in Dissipative Media with Electrically Short Probes, *C. K. H. Tsao, J. T. deBettencourt*—In a dissipative medium, the RF input conductance of a linear dipole, whether a bare wire or an insulated wire with its terminals short-circuited to the medium, is simply related to the conductivity of that medium, provided the electrical length of the dipole is short. Model measurements were made on dipoles in saline water of known conductivity to test the theory. The feasibility of deducing conductivity of the solution by using both antenna types as probes was demonstrated. The technique has been utilized to evaluate the electrical conductivity of rock media from measurements on probes inserted into vertical drill holes. Examples are given of measurements variously to depths of 4000 feet. In one of the cases the rock type was (fractured) granite and, in another, anorthosite. In a geophysical crustal sense, data are typical of some near-surface or sedimentary rock conditions. Since such rock media are rarely uniform in their electrical characteristics, the deduced conductivity will be a gross average conductivity of that volume of the rock approximately within the antenna region of the probe.

Microsecond Clock Comparison by Means of TV Synchronizing Pulses, *J. Tolman, V. Ptáček, A. Souček, R. Stecher*—A new method for precise clock comparisons is described, making use of the short rise time of the synchronizing pulses of a current television picture signal. It is shown that by measuring simultaneously the time interval between one and the same selected television frame synchro pulse and the pulses derived from the respective clocks, these clocks may be compared with microsecond accuracy even if widely separated, provided appropriate correction for the travel time of the synchro pulse is applied. An experiment concerning international clock comparison between Prague and Potsdam is described and the numerical results presented. Synchronization of clocks (separated by about 300 km) to about 2 μs was accomplished, and it appears that 0.1 μs is feasible. Further possible applications of this method are discussed.

On a Method of Estimating Power Spectra, *T. C. Hsia, D. Landgrebe*—A method of estimating power spectral density functions of discrete stationary random processes is given. The spectral density functions, formulated in sampled-data form, are represented by a ratio of two real polynomials in z. The main objective is to estimate a set of unknown parameters in the spectral density function from a finite measurement of the random process. It is assumed that no knowledge about the probability distribution of the random process is required. An estimation scheme is developed based on the theory of stationary time series. Both numerical and analytical methods are used for the solution. The parameters in the denominator and numerator are estimated in two separate steps. The advantage of this result is twofold: The dimensionality is reduced in each stage of estimation, and the interaction between the parameters of the numerator and that of the denominator is avoided. An example is given to demonstrate the estimation procedures.

A Technique of Measurement of Impedance Through a Lossless Transition, *T. J. Russell*—A method is presented for the measurement of impedance through a transition from the slotted section transmission line to the load transmission line. The technique uses a lossless tuner as part of the transition and a precision transmission-line section. An example of a practical application of the method is given.

The Accuracy of Series and Parallel Connections of Four-Terminal Resistors, *J. C. Riley*—The range and accuracy of resistance calibration can be increased by the use of series and parallel connections of four-terminal resistors. Low-value resistors can be permanently connected in series and reconnected in parallel by using Hamon's technique to change resistance level without materially affecting resistance accuracy. The resistors are connected in parallel with short-circuiting bars to one terminal at each end, and matched resistors are connected in series with the other terminals. High accuracy can be attained even though lead and connection resistances are relatively high. A theoretical base and an error analysis are provided to justify the use of the series to parallel transfer technique at low-resistance levels. The analysis uses a four-terminal equivalent circuit suggested by Searle. The accuracy of series and parallel connections of groups of like resistors is investigated in terms of the equivalent circuit. Procedures are developed for determining the connection accuracy of a set of resistors in parallel or series.

IEEE Transactions on Microwave Theory and Techniques

Vol. MTT-15, no. 10, October 1967

Tunnel-Diode Low-Level Detection, *W. F. Gabriel*—An analysis of tunnel-diode low-level detection is presented for the purpose of explaining some of the unusual detection characteristics that occur under certain bias conditions. For example, in the vicinity of its inflection bias point, a tunnel diode exhibits a discriminator-like rectification behavior with two sensitivity peaks. When biased at one of these peaks, the diode is capable of unusually high sensitivities, at least an order of magnitude better than the sensitivity of any other known diode. It is shown that these high sensitivities are proportional to $(1 - \Gamma^2)$, where Γ^2 is the RF power gain of the detector viewed as a reflection-type amplifier. The resultant gain–bandwidth (or sensitivity–bandwidth) limitations of the detector are discussed. Unusually high sensitivities are also possible at the lower microwave frequencies when the tunnel diode is biased at its peak current point. A knowledge of the diode static characteristics, the reflection coefficient, and the video circuit permits an accurate analytical evaluation of the sensitivity performance of any tunnel diode, and calculations are carried out for an example diode and compared against measured data. A specific comparison of the relative sensitivity performance of the example tunnel diode versus a hot carrier diode is included.

A Design Technique for Realizing a Microwave Tunnel-Diode Amplifier in Stripline, *B. A. Miller, T. P. Miles, D. C. Cox*—A significant problem in realizing a practical tunnel-diode amplifier is that of stabilizing the amplifier both within and outside its passband while maintaining a specified center-frequency gain and bandwidth. A new technique for realizing a moderate-bandwidth tunnel-diode amplifier that utilizes a directional filter as a bandpass structure is described. This technique was investigated analytically and an experimental *S*-band amplifier was built and tested. This experimental amplifier had typically the following characteristics: bandwidth, 400 MHz; center frequency, 2.9 GHz; and center-frequency gain, 12.5 dB. The technique described yields an amplifier that is reproducible and that has an analytically predictable and well-defined response. None of the experimental models have shown any tendencies toward oscillations.

The Overdriven Varactor Upper-Sideband Upconverter, *A. I. Grayzel*—The equations for the overdriven upper-sideband upconverter are derived and computer solutions are given for the abrupt junction, graded junction, and punch-through varactor. The necessary design parameters are presented for the design of an upconverter. The performance of the abrupt, graded, and punch-through varactors are compared.

An Adjustable Narrow-Band Microwave Delay Equalizer, *T. A. Abele, H. C. Wang*—A simple low-loss microwave delay equalizer for the delay equalization of narrow-band microwave bandpass filters has been explored. This equalizer is quite small and does not require the use of additional components such as circulators or hybrids. It exhibits a reflection coefficient of less than 1 percent and possesses two very valuable and convenient features: a continuous adjustment of the delay shape and of the center frequency. The structure is analyzed theoretically, an equivalent circuit is derived, and expressions for both delay and loss are given. Also presented are design data and experimental results concerning the actual delay equalization of a bandpass filter and the temperature behavior of the equalizer and the filter–equalizer combination.

The Accuracy of Finite-Difference Solutions of LaPlace's Equation, *W. J. Duncan*—The cross sections of most TEM mode transmission lines have re-entrant corners or edges where the potential gradient is singular. The accuracy of the finite-difference solution for the electric field normal to the conductor boundary at a right angle corner and at the edge of a thin plate is examined. The accuracy of the finite-difference solution is related to the mesh length h, the magnitude of the lattice point residuals, and the finite-difference operator, which is used in place of the Laplacian differential operator. The computing time required to solve the mesh equations by the method of successive over-relaxation is specified. The surface charge density in the neighborhood of the boundary singularity is expressed as a truncated series of circular harmonics. As a result, the integral of the surface charge can be calculated with very good accuracy. The harmonic series treatment is used to determine the capacitance per unit length of a square coaxial transmission line.

Correspondence

The Negative Capacitor, An Impedance Matching Element for Dielectric-Filled Transmission Line, *A. J. Kelly*
High-Power S-Band Power Divider, *R. M. True*
Controlled Wideband Differential Phase Shifters Using Varactor Diodes, *C. A. Liechti, G. Epprecht*
Bandwidth Curves for Mumford's Maximally Flat Filter, *B. M. Schiffman*
Design Curves for Waveguide Absorbers, *H. R. Witt, E. L. Price*

IEEE Transactions on Nuclear Science

Vol. NS-14, no. 5, October 1967

Collection Time of Electron-Hole Pairs in a Coaxial Ge(Li) Radiation Detector, *D. N. Poenaru*—Current and electric charge pulse shapes obtained for the collection of only one electron-hole pair released by an ionizing event in the sensitive volume of a coaxial Ge(Li) detector cooled at liquid nitrogen temperature, were calculated. By considering the pairs generated in the close vicinity of the detector electrodes as well as those created in an intermediate region, maximum and minimum durations of the current pulses have been found. Low electric field intensity is assumed (charge carrier velocity directly proportional to the electric field intensity).

A Portable Neutron Dose Equivalent Meter, *E. J. Rogers*—A portable, battery-operated fast neutron monitor has been developed for use at reactors and accelerators. The instrument employs a polyethylene-loaded proportional counter and reads directly in biologically equivalent units for neutrons from 0.1 MeV to over 15 MeV on eight scales ranging from 2 mrem per hour to 6000 mrem per hour. On the lower ranges, the input pulses are integrated for electronically determined time intervals, and on the higher ranges, a rate-meter mode of operation is employed. All of the electronics, including the 1400-volt power supply for the proton-recoil-type detector, require only 25 milliwatts of power, permitting about 500 hours of continuous operation from a small 7-volt mercury battery. Electronic voltage regulation and the use of field-effect transistors in the integrating and timing circuits provide a stability of calibration far beyond that normally associated with portable survey instruments.

Permanent Radiation Damage Effects in Narrow-Base PNPN Devices, *D. K. Wilson, H. S. Lee*—The effect of fast-neutron radiation damage in narrow-base PNPN devices were measured and compared with a simple, one-dimensional theory for PNPN devices, based on the work of Kuz'min. The limitations of a PNPN device in a radiation environment are primarily determined by the increase forward "on" voltage. A reasonably good fit of observed and calculated "on" voltages for a variety of PNPNs was obtained using a silicon lifetime damage constant of $\approx 10^6$ sec-N/cm². Design considerations for radiation-resistant PNPNs are discussed, and devices capable of operating after exposure to more than 10^{15} neutrons/cm² are described. PNPNs are shown to be superior to bipolar transistors as power switches in a radiation environment.

An Inductive Energy Storage System Using Ignition Switching, *E. Simon, G. Bronner*—Previous work in the field of inductive energy storage and control is described. The need for a fast, reliable switch for the control of such systems is pointed out. A new inductive energy storage switching system that fulfills this need is described. The new system utilizes an ignitron bridge circuit and a capacitor to invert from the unidirectional current of an inductive source to an alternating voltage of triangular waveform. The alternating voltage is used to charge and periodically recharge a small capacitor. This capacitor in its turn supplies energy to the load. Thus, by the use of two capacitors, whose maximum stored energy is very small compared with the total energy to be transferred, the stored energy may be transferred to the load in discrete parcels. The disassociation of storage and load circuit allows the transfer of all stored energy to the load, with the exception of the usual resistive energy loss imparted by circuit elements, a quantity that can be kept small. Therefore, the energy efficiency is higher than heretofore attained by inductive energy storage systems. The switching system does not depend upon moving contacts or mechanical devices. It results in significant reductions in initial cost per joule of energy stored as compared with the cost of capacitive energy storage systems. The inherent low energy efficiency of earlier inductive energy storage systems is discussed and it is pointed out that the theoretical energy efficiency of the bridge scheme is much higher. Current relations in the circuit during charge and during transfer are described. A small-scale prototype has been constructed and was found to operate satisfactorily. Oscillograms of currents and voltages present in this circuit are shown. Techniques for the optimization of the various circuit parameters are also discussed briefly.

IEEE Transactions on Power Apparatus and Systems

Vol. PAS-86, no. 8, August 1967

Recovery Strength Measurements in Arcs from Atmospheric Pressure to Vacuum, *G. A. Farrall, J. D. Cobine*—Measurements for the recovery of electric strength following interruption of an arc drawn in nitrogen at pressures ranging from atmospheric to 0.02 torr are reported. These data are compared with similar results obtained for vacuum arcs. Recovery strength measurements followed a single half-cycle of sinusoidal arc current with a peak of 400 amperes. For conditions of gap length and pressure described by the Paschen curve minimum, full recovery is reached in a time less than a few microseconds. The voltage corresponding to full recovery is essentially determined by contacts, their separation, and ambient gas pressure.

Switching Surge Flashover Characteristics of Extremely Long Air Gaps, *Y. Watanabe*—An estimate is made of the limit of the possible transmission-line voltage and the mechanism of discharge in the air is clarified. Tests were performed on the switching surge flashover of long air gaps under dry conditions. The flashover voltages of the switching surge with the duration of wavefront 180 μs were obtained up to 13 meters for rod-plane gaps for positive polarity. The tests were performed at the Shiobara Outdoor Laboratory.

Influence of Air Density on Line-to-Ground Switching Surge Strength, *L. Paris*—A series of tests, which were carried out by applying impulse waves simulating switching surges to air gaps with electrodes of different shapes, is described. From the test results it has been possible to draw some important conclusions about the influence of the electrode shape and also to single out simple rules for predetermination of the behavior of air insulation. These rules can be particularly useful for designing purposes.

Influence of Air Density on Electrical Strength of Transmission-Line Insulation, *T. A. Phillips, L. M. Robertson, A. F. Rohlfs, R. L. Thompson*—Flashover tests were conducted at the Leadville EHV Test Facility of the Public Service Company of Colorado and Project EHV at Pittsfield, Mass., to obtain comparative data to evaluate the influence of air density on the switching-surge and impulse flashover strength of transmission line insulation. The tests showed that negative polarity switching-surge flashover voltages are greater than those of positive polarity. Therefore, positive polarity will be the critical requirement for transmission-line design for switching-surge duty. Air density corrections ranging from $(RAD)^{0.6}$ to $(RAD)^{1.0}$ were found for positive polarity switching-surge voltages as a function of insulation length and configuration. For impulse voltages, a full air density correction is required for both polarities under all conditions, with the exception of negative polarity where with a massive proximity effect no air density correction is required.

Determination of Characteristic Voltages in Impulse and Switching Surge Testing, *J. A. Bakken*—The characteristic impulse and switching surge voltages of high-voltage equipment that only temporarily loses its dielectric strength when flashover occurs are dealt with. A test procedure suitable for determining the highest withstand voltage and the lowest flashover voltage of a test object is described, and a theoretical investigation is carried out in order to show the quality of the test procedure, and also the influence from different factors on the test result. The relation between the specified withstand voltage of a test object, as defined by IEC, and the highest withstand voltage is given some consideration. A simple method for determination of the 50 percent flashover voltage is described.

The Confidence Limit of High-Voltage Dielectric Test Results, *E. Brasca, M. Tellarini, L. Zaffanella*—The knowledge of uncertainty of high-voltage dielectric test results is emphasized. The uncertainty can be expressed by a suitable confidence limit. The best figure suggested is the standard deviation σ of all the possible results of a test. A method for the calculation of σ is reported. Four types of confidence limits are considered and the values reported on the basis of available data from CESI and many other laboratories. The spread of the results is found higher than previously expected. A survey of apparent causes of the uncertainty is presented but a series of unknown factors must be supposed to justify the figures found. Examples of application indicate the usefulness of the knowledge of the confidence limits of the test results.

Analysis of Spark Breakdown Characteristics for Sphere Gaps, *A. Pedersen, J. Lebeda, S. Vibholm*—The application of a semiempirical spark breakdown criterion is illustrated, and it is shown that it can give a very detailed analysis of known spark breakdown characteristics for the sphere gap. Measurements are reported on scattering in impulse voltage for a sphere gap having a length of 25 cm. The results give new evidence for the existence of the Toepler discontinuity.

Economic Optimization of Transmission Tower Grounding and Insulation, *G. E. Grosser, Jr., A. R. Hileman*—A reduction in transmission-line cost was thought possible through a unified approach to line insulation system design. A mathematical model relating line performance to insulation system expenditure is analyzed and using incremental cost techniques a method for optimizing the selection of insulation system components to achieve a desired performance or reliability level is developed. The development provides an insight into the interaction of tower grounding and tower insulation in establishing the reliability of a line.

Line Insulation Design for APS 500-kV System, *A. R. Hileman, W. C. Guyker, H. M. Smith, G. E. Grosser, Jr.,*—An attempt has been made to obtain an optimum insulation system that fulfills all APS requirements. The three primary areas that dictate insulation design limits are normal frequency voltages and contamination, switching surges, and lightning. Contamination limits were established by an extrapolation of operating experience at other voltage levels. The switching surge limits were established by miniature system studies coupled with experience gained in laboratory and field tests. The lightning performance was calculated using accepted methods and optimum improvement was obtained by using an incremental cost method to evaluate the cost of improved grounding, increased numbers of insulators, and better shielding angles. The respective design limits were then coordinated into a final design.

EHV Application of Autotransformers, *G. W. Alexander, W. J. McNutt*—The universal method of voltage transformation from EHV levels to lower voltage systems is through the use of the autotransformer. The characteristic of the autotransformer is profoundly influenced by the tertiary winding or the lack of it. The influence of the tertiary winding and its placement, fault magnitude and short-circuit duty, autotransformer loading, overexcitation, protection of unloaded tertiaries, loading of paralleled autotransformers, and the use of single-phase units while presenting a circuit for studying unequal impedances in paralleled banks are discussed.

Comparison of 60-Hz Field Measurements with Digital Analysis of 500-kV Transmission Line, *F. W. Smith, L. McKenzie, D. Coleman, R. B. Shipley*—Power system studies involving economics, stability, short circuits, load flows, etc., require a knowledge of transmission-line characteristics. Traditionally, these characteristics have been determined either by field tests or by mathematical computations. The construction of a 118-mile bundled EHV line between Johnsonville and Memphis, Tenn., afforded a much needed opportunity to compare tested line characteristic values against digitally computed values. The comparison is of industry interest because of the increasing use of digital computers for such calculations.

Effect of Station Radio Noise Sources on Transmission-Line Noise Levels—Experimental Results, *J. Davey, H. L. Deloney, J. J. LaForest*—Known sources (gaps) of radio noise (RI) generation were applied to a transmission line close to a station and the resultant transmission line RI levels were monitored. Measurements were in good agreement with calculated values. Measurements of station impedance were also made. The RI gaps were found to be stable and operated as constant-current generators over a considerably wide range of load impedance values.

Probabilistic Aspects of Transmission System Switching Surge Reliability, *A. J. McElroy, J. H. Charkow*—Probabilistic principles are applied to predicting the transmission system flashover rate caused by switching operations by combining results of laboratory tests on component insulation structures with system overvoltage probability distributions. A piecewise normal method is developed, applicable when statistical dependence of insulation structure flashover and system overvoltage generation cannot be described by standard normal distributions over the entire specified range of voltages. Results are obtained for large numbers of insulation structures in parallel and, by appropriately synthesizing the described subsystems, entire transmission systems can be analyzed. The effect of voltage-limiting devices, such as arresters, has been studied and their effect on system performance can be included in the analysis.

IEEE Transactions on Power Apparatus and Systems

Vol. PAS-86, no. 9, September 1967

Design Stresses and Current Ratings of Impregnated Paper-Insulated Cables for HV DC, *S. C. Chu*—An investigation into the designs and current ratings of oil-impregnated paper-insulated cables for various direct-voltage ratings and impulse withstand levels is described. Published information on the temperature and stress coefficients of resistivity is reviewed. Methods of calculation of the stress distribution are outlined. With the aid of a digital computer, data, including the maximum screen stress at various maximum conductor temperatures, have been obtained for a range of conductor sizes.

Glass-Reinforced Epoxy-Resin Pipe for Pipe-Type Cable, *R. B. Blodgett, J. Sasso*—Cable engineers have recognized for many years that losses that occur in the steel pipe of pipe cable systems appreciably increase ac resistance and greatly reduce possible ampacity of such systems. Nonmagnetic pipes did not offer a practical solution to the problem, since available materials contributed essentially the same degree of loss to the system as steel pipes. Hence, from time to time, engineers have focused their attention on nonmetallic pipes as a means of reducing losses. The work discussed shows that one of three plastic pipes examined effectively stopped the entrance of moisture and caused no deterioration of the cable or pipe oil. Therefore, from a technical standpoint, it provided an effective enclosure for pipe cable. However, the cost of such pipes is still too high to make them economically feasible.

Underground Distribution Thermal Tests in Phoenix Area, *N. R. Schultz, J. F. Thomas*—The results are summarized of an 18-month thermal test program, conducted jointly by the Arizona Public Service Company and the General Electric Company, to investigate thermal characteristics of soil and performance of underground equipment in the Phoenix area. The results presented include earth ambient temperatures at various depths over an annual cycle, earth thermal resistivity measurements by steady-state and transient methods, performance of direct burial and vault installation of capacitors, performance of a directly buried, 25-kVA, pole-type distribution transformer, and temperature rise of simulated cables.

Lightning Protection of Underground Residential Distribution Circuits, *R. W. Powell*—General studies have been made on the analog computer to determine the maximum permissible cable lengths with which equipment can be protected by lightning arresters at only the line-cable junction. Arrester application tables, derived from computer results, for underground residential distribution systems, are presented.

The Effect of Test and Abnormal System Voltages on Transformer Insulation, *F. S. Young, T. W. Dakin, H. R. Moore*—In service, a transformer will be subjected throughout its life to three different types of voltages. These are: power frequency, switching surge, and impulse voltages. Recent computer studies and field investigations of EHV systems have provided data on the magnitudes and durations of these voltages. Laboratory tests and factory tests of transformer insulator structures have provided new data on performance. Impulse test levels have been defined for many years. Modern lightning arresters can be selected to provide adequate protection against switching surges. The area, presently ill defined, relates to long-time power-frequency overvoltages. Factory test levels that are currently based on BIL and not system voltage can be replaced by a more meaningful test. The voltage level of this test should be selected to provide adequate margin above any overvoltage encountered in service.

Determination of Thermal Life Expectancy of Overhead Distribution Transformers, *D. O. Craghead, W. A. Erskine*—The calculated thermal life expectancy of distribution transformers is used by the Southern California Edison Company as part of an evaluation program to develop a comparative basis for the economic purchase of annual transformer requirements. The test procedure utilized in accelerating the thermal aging of the transformers, the pretest measurements, the test measurements, and the mathematical derivation of the transformer aging rate as demonstrated by its performance on the accelerated test is described. In addition to the test procedure, a simulated residential loading schedule has been developed and is used to calculate the expected life of each test transformer. A tabulation is used to demonstrate how the calculations are made and to provide a comparison of the life expectancy of two typical transformers.

Relation of AC Losses to Hysteresis Losses in Electric Sheel Steels, *F. R. Richardson, E. C. Falkowski*—The application of dimensional analysis to measurements made on cold rolled electrical steels yields empirical equations relating ac core losses to hysteresis losses and other factors. As frequency increases from low values, three different patterns of loss variation occur because of increasing skin effect. Loss measurements indicate that samples with lower hysteresis losses and thinner gauges have relatively larger magnetic domains. The hysteresis losses of well-annealed samples are found to depend primarily on the sizes of the grains and their orientations. The steels that were investigated have only incidental amounts of grain orientation.

A Numerical Analysis of Hysteresis and Eddy Current Losses in Solid Cylindrical Rods of No. 1010 Steel, *M. D. Abrams, D. H. Gillott*—A procedure is outlined that utilizes the digital computer to solve eddy current loss and hysteresis loss problems. The relationship between flux density and magnetic intensity is taken from the actual magnetization curve and major hysteresis loop, thus eliminating the approximations employed in most previous investigations. The nonlinear partial differential equations are replaced by finite difference equations and solved by numerical methods on an IBM 7090 digital computer. The loss calculations presented are made for a round rod employing a sinusoidally varying (60-Hz) magnetic field intensity as the driving function. To verify the results, total losses calculated are compared with test results and with results obtained by a numerical procedure which neglects hysteresis effects.

500-kV Line Design: I—Insulation Characteristics of Tower, *Y. Saruyama, M. Yasui, G. Ikeda, S. Nagasaki, N. Mori*—The results of tests using a full-scale transmission line for the insulation design of the first 500-kV transmission line in Japan (the Boso Line of Tokyo Electric Power Company) are described. Having clarified the switching surge and impulse flashover characteristics of V-string insulator and strain insulator assemblies, installed on a simulated tower with a long gap of 3 meters or more, insulation was designed that withstands a switching surge of 2.5 per unit and is capable of unbalanced insulation between vertically arranged double circuits. The flashover path, predischarge, etc., of the switching surge was also investigated.

500-kV Line Design: II—Corona and RIV Characteristics of Insulator-Hardware Assemblies, *Y. Saruyama, M. Yasui, S. Nagasaki*—The corona noise characteristics of insulator-hardware assemblies on the Boso Power Transmission Line of Tokyo Electric Power Company, which is the first 500-kV transmission line in Japan, is described. The results of corona noise measurement made on a V-string insulator assembly are reported. Data on the corona noise level of insulator hardware obtained from a test line were converted into noise level values for an actual transmission line for comparison with the conductor corona noise levels. The design of the insulator hardware was selected accordingly.

Arc Resistance of FRP and Application of FRP to Arms in Overhead Power-Line Tower, *H. Okamoto, Y. Ikeda*—Concerning the application of insulation arms to overhead transmission structure some tests on the arc-resistance nature of insulating materials have been performed, mainly by means of a plasma jet generator. Several materials were exposed to the plasma flame and the state of the surface degeneration was examined. From the results, the relation between arc resistivity and the chemical structure of materials has been clarified to some extent. This fundamental information yields some excellent fiber-g ass-reinforced plastics (FRP) under actual arc discharge. The insulation arms made of improved FRP have been used successfully on actual overhead line towers as a tension crossarm member to compensate for the lack of clearance.

Pyrolysis of Stator Coil Insulation in Air and Hydrogen, *M. M. Fromm*—The study of changing properties of generator stator coil insulation on long-time exposure at elevated temperature is an accepted part of insulation development. This aging, however, has usually been done in air, whereas the windings of modern turbine generators operate in hydrogen atmosphere. Samples of synthetic-resin-bonded insulation were pyrolyzed in air and hydrogen at 200°C and one atmosphere. The gaseous, liquid, and residual products were analyzed by chromatography and infrared spectroscopy. Heated in air, the gases contained C_3, C_4, and C_5 straight chain hydrocarbons, but the products in hydrogen contained, in addition, cyclohexane. The liquid and residual products indicate that the sample pyrolyzed in air degrades by depolymerization and oxidation, whereas the sample in hydrogen depolymerizes, followed by some degree of hydrogenation.

New Power Cable Insulations Based on Covulcanized Blends of Ethylene Propylene Rubber and Polyethylene, *M. L. Singer, S. L. DiVita*—New power cable insulations based on covulcanized blends of ethylene propylene rubber and polyethylene have been developed. These heat-, water-, ozone-, and highly corona-resistant insulations combine many of the desirable properties of both ethylene propylene rubber and polyethylene. Specific constructions of low-voltage heat- and moisture-resistant power cables, aerial spacer cables, and portable power cables are reviewed and compared with existing constructions. It is felt that, compared with rubber-insulated cables, the use of these new insulations can result in smaller-diameter cables, which exhibit many improved properties over thermoplastic or cross-linked polyethylene cables.

Thermal Characteristics of Two Types of Concrete Conduit Installations, *D. D. Nagley, R. J. Nease*—A field installation of two different types of underground duct banks was made. They differed only in the spacing between the ducts and in the amount of concrete used in their thermal circuits. Identical loading was applied to each duct bank and studies were made of thermal gradients around them as determined by thermocouples. Differences in their thermal capabilities were shown to be due to different degrees of drying in soil or concrete in close proximity to the loaded ducts. Possible corrective measures to obtain better thermal conditions and a method of calculating thermal capabilities are presented, using previously published equations.

New Techniques in the Termination of High-Voltage Power Cable, *E. H. Yonkers*—The advent and expanding use of synthetic-polymer-insulated high-voltage power cable has created a need for improved means for terminating this type of cable. The characteristics of synthetic polymer insulation permit the use of new techniques and materials that make it possible to design cable accessories with significant improvements in installation convenience as well as in functional characteristics. Specific devices for terminating polymer-insulated cable employing such new materials and techniques are described in detail.

A New Termination for Underground Distribution, *L. G. Virsberg, P. H. Ware*—A new principle for stress control on cable terminations has been devised. A tape having a nonlinear voltage–current characteristic is wrapped on the exposed cable end. The resistance of this tape varies with stress in such a manner that the stress along it tends to equalize. A mathematical study of the voltage distribution along the termination is reported, and the conclusions are borne out by the results of calculations made on an analog computer. Service experience in Europe has proved satisfactory, and a laboratory evaluation in the United States has shown this new type of termination to be technically equal to or superior to standard methods of terminating underground residential distribution cables, even under wet and contaminated conditions. The physical requirements for a terminating tape are discussed, along with comments on suitable dimensions, methods of tape application, and noise from electrical sources associated with the tape. The calculation of voltage distribution is explained in the appendix.

IEEE Transactions on Reliability

Vol. R-16, no. 2, September 1967

A Monte Carlo Technique for Obtaining System Reliability Confidence Limits from Component Test Data, *L. L. Levy, A. H. Moore*—A digital computer technique is developed, using a Monte Carlo simulation based on common probability models, with which component test data may be translated into approximate system reliability limits at any confidence level. The probability distributions from which the component failures are assumed to come are the exponential, Weibull (shape parameter K known), gamma (shape parameter α known), normal, and log-normal. The components can be arranged in any system configuration, series, parallel, or both. Since reliability prediction is meaningful only when expressed with an associated confidence level, this method provides a valuable and economical tool for the reliability analyst.

Performance Simulation Involving Correlated Part Characteristics, *A. C. Nelson, Jr., J. R. Batts*—In the analysis of an electronic circuit containing component parts on which two or more measurements are made there is the need for treating correlated part characteristics. In a performance simulation analysis using a digital computer, one must generate the correlated variables with the appropriate correlations. A method for generating a set of normally distributed variables with a given correlation matrix is presented. The method is based on an algorithm used in the square root method for solving a system of linear equations. The procedure is applied to a linear amplifier, for which the h parameters of the equivalent dc circuit analysis of the transistor are a good example of correlated part characteristics. The method has been written in Fortran and the computations could be performed on almost any digital computer.

The Uncertainty of System Failure-Rate Predictions, *D. M. Brender*—The relative uncertainty involved in the prediction of the failure rate of a system is often considerably less than the uncertainty associated with the failure rate of the average component. For example, if we are 60 percent uncertain of the failure rate of each of nine component types, then, at best, we are only 20 percent uncertain of the system failure rate. This result is a consequence of the variety of component types, not the number of each type present in the system. The relative uncertainty associated with the prediction of the number of future system failures is always greater than the relative uncertainty associated with the system failure rate. As an example, let the uncertainty in the system failure rate be 20 percent. If, using the estimated failure rate as the true failure rate, the Poisson process yields a 40 percent uncertainty in the number of failures for an interval t_1, then the actual uncertainty is 45 percent; if, for a larger interval t_2, the Poisson process yields 10 percent, the actual uncertainty is 22 percent. The fault is not with the Poisson process, but rather with the assumption that the estimated failure rate can be treated as the true failure rate.

Optimization of Systems Reliability, *L. T. Fan, C. S. Wang, F. A. Tillman, C. L. Hwang*—The purpose stated is to obtain an optimum redundancy of the parallel system by a variational technique. The objective function is to maximize the system profit. A simple computational procedure is obtained for the optimum design of the multistage parallel systems by this method. Two numerical examples are given in detail.

Bayesian Confidence Limits for the Reliability of Cascade Exponential Subsystems, *M. D. Springer, W. E. Thompson*—The problem treated is that of deriving exact Bayesian confidence intervals for the reliability of a cascade system consisting of N independent subsystems each having an exponential distribution of life with a failure rate that is estimated from life test data. The posterior probability density function of the system reliability is derived in closed form, using the method of the Mellin integral transform. The posterior distribution function is obtained, which yields Bayesian confidence limits on the total system reliability. These results, which are believed to be new for $N > 3$, have an immediate application to problems of reliability evaluation and test planning.

IEEE Transactions on Sonics and Ultrasonics

Vol. SU-14, no. 4, October 1967

The Design and Application of a Reliable Ultrasonic Atomizer, *R. R. Perron*—The design and performance of a 56-kHz ultrasonic atomizer are presented. The approach taken to achieve high efficiency, reliability, and long transducer life is given; and the effect of frequency and tip amplitude on the performance of atomization is discussed. Application of the atomizer to a reliable low-rate oil burner and a unique drop formation experiment is described.

Variational Method for Electroelastic Vibration Analysis, *E. P. EerNisse*—The calculus of variations is applied to the analysis of the short-circuit resonant properties of piezoelectric vibrators. A stationary expression is derived from the equations of motion for such vibrations. This stationary expression is used to develop a variational approximation technique for determining the short-circuit resonant frequencies and the corresponding mechanical displacements and electric potentials. The technique is used to analyze the short-circuit resonant properties of fully electroded piezoelectric ceramic disks with comparable diameter and thickness dimensions. Agreement of the barium titanate resonant frequency calculations with Shaw's published experimental frequency spectrum is better than three percent for the lowest eight resonances. Also, exact solutions have been obtained for the equivoluminal modes supported in isotropic elastic disks of certain diameter-to-thickness ratios. The application of the elastic portion of the present electroelastic approximation to such disks produced frequency values for these modes that agree with the exact values to better than 0.3 percent.

Backward-Wave Parametric Interaction Between Longitudinal and Transverse Elastic Waves, *A. E. Lords, Jr.*—The parametric interaction between a continuous, forward-traveling longitudinal elastic wave pump and continuous, forward- and backward-traveling transverse elastic waves is considered. The coupling between the waves is provided by third-order terms in the elastic energy density. Using "typical" values for loss and nonlinearity, and omitting all reflected waves in the analysis, the threshold value of longitudinal wave pump at 3 GHz needed to generate the two transverse waves from the thermal background is calculated. Also, amplification coefficients for either forward- or backward-traveling transverse signal waves are calculated for a 3-GHz pump and for various pump amplitudes and interaction distances. It appears that amplification is only practical for a continuous-wave, pump strain amplitude of at least 10^{-6}, which, with current experimental practice, is probably too high to realize. If, however, continuous-wave strain amplitudes this large could be realized, and if a reflectionless-experimental situation could be achieved, the analysis shows that a high-gain, parametric transverse elastic wave amplifier could be constructed. The high-gain region could be achieved by operating the device very near to the conditions where it becomes a "backward-wave oscillator."

Elastic and Piezoelectric Characteristics of Bismuth Germanium Oxide $Bi_{12}GeO_{20}$, *M. Onoe, A. W. Warner, A. A. Ballman*—Room temperature values of the elastic, piezoelectric, and dielectric constants of bismuth germanium oxide have been determined. All of the elastic and piezoelectric constants were determined from dynamic measurements of piezoelectrically driven thin plates of various orientations. Specific combinations of electrode configurations and plate orientations yielding pure thickness-shear and thickness-extensional vibrations are considered. The usefulness of this material for ultrasonic device applications is discussed.

Transmission Parameters of Thickness-Driven Piezoelectric Transducers Arranged in Multilayer Configurations, *E. K. Sittig*—The individual transducers of an ultrasonic delay line may consist of a multiplicity of piezoelectrically active layers electrically connected in series, parallel, or grouped in series–parallel combinations interspersed with electrically conductive or nonconductive layers of different characteristic acoustic impedances. The stack of transducer layers may be loaded by an absorptive or reactive backing and coupled to the delay medium through bonding and matching layers. The transmission parameters for such configurations are written in a form well suited to digital computation. Inspection of numerical results reveals effects that may be qualitatively understood by visualizing separately the effects due to the mechanical resonances of the layer assembly and those due to the arrangement of piezoelectric material with respect to the stress distribution within the stack. The examples given indicate that transducers consisting of alternately poled stacked $\lambda/2$ layers of a low coupling factor material such as CdS give an insertion loss improvement at the cost of bandwidth reduction little different from that obtained with narrow-band tuned terminations. For high coupling factor layers, no significant improvement is obtainable.

Acoustic Drying of Coal, *H. V. Fairbanks, R. E. Cline*—It is estimated that millions of tons of coal fines are discarded each year due to the difficulty of drying them economically with conventional mechanical dewatering and thermal drying equipment. This is due to the fact that coal of small particle size presents a large surface area with polar groups that increase the amount of adsorbed water to be removed. Since thermal dryers are more effective in the removal of absorbed water than adsorbed water, the effectiveness of thermal dryers is reduced when drying coals of finer mesh sizes. There is also more danger of explosion when thermal drying fine coal due to the large amount of reactive surface available. Since acoustic energy has the property of producing cavitation at a liquid-solid interface, it was conjectured that the application of acoustic energy during the drying process might prove to be of value. This cavitation process produces water vapor at room temperature that could be carried away from the solid surface by a flow of relatively cool air. Alma coal, having a particle size range of −100 +200 mesh and −200 mesh, was used in this investigation. The coal was mixed with water to produce moisture contents ranging from 6 to 30 percent water on a dry basis. This moist coal was then subjected to acoustic drying at frequencies of 20 kHz and 12 kHz. The duration in the sound fields varied from one to twelve minutes. Room temperature was used in all experiments except in a factorial design experiment in which temperatures of 25°C and 75°C were used.

IEEE Journal of Quantum Electronics

Vol. QE-3, no. 9, September 1967

Long-Term Operation of a Sealed CO_2 Laser, *R. J. Carbone*—The life expectancy of a sealed CO_2 laser tube depends, to a great extent, on the interaction of the molecules existing in the discharge at the cathode. The data reported indicate that after operation of a sealed laser, only CO and O_2 are formed in concentrations comparable to the initial fill gases of CO_2, N_2, and He. The CO, CO_2, and O_2, in particular, were found to be completely adsorbed at the Ni cathode within several hundred hours of tube operation. A loss of 10.6-μm power output accompanied this adsorption. As expected, the process was reversible to a degree since the laser resumed operation at the initial power level after the cathode region had been heated to 300°C. This process of adsorption–desorption was repeated several times up to an accumulated operating time of 705 hours. During this time, the power output remained at a substantially constant value. However, the loss of CO_2 by carbon deposits ultimately means an end to tube life.

Proposal for Generation of Intensive Single-Frequency Beam by Second-Harmonic Generation of an FM Laser Beam, *H. P. Weber, E. Mathieu*—An arrangement that allows the generation of a single-frequency beam at the second harmonic is proposed. Essentially, frequency addition is performed of two signals that are frequency modulated with equal and opposite frequency excursion. For maximum efficiency, the modulator and the nonlinear crystal are arranged inside optical resonators for fundamental and harmonic frequencies.

Correspondence

Vibrational Excitation of CO_2 by Transfer from Thermally Excited Nitrogen, *G. Makhov, I. Wieder*

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*Electrical and electronics engineers and scientists who have a knowledge of Russian or Japanese and who are willing to translate on a free-lance basis for Scripta Electronica should apply to the IEEE Special Subscription Department.

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Reviews

Telecommunications and Radio Engineering Part I—Telecommunications

Vol. 20, no. 7, July 1966

Picture Distortion in Television Standards Conversion, *N. K. Ignat'yev, E. Z. Soroka*—This article analyzes the vertical resolution obtainable in the conversion of television pictures from one scanning standard to another. Originally, converters were optical, producing an actual picture in the first standard, which was then scanned in the second standard by conventional cameras. Subsequently, electronic converters have been developed for use where the field frequencies are the same for the two standards.

The paper employs Fourier transforms to analyze the vertical resolution obtainable, and concludes that when conversion is performed on a field-to-field basis, as is the case with present electronic converters, the overall vertical definition is reduced by one-half. Restoration of the full vertical definition would require frame-by-frame conversion, but at present this can be accomplished only on an optical and not an electronic basis.—*Howard T. Head*

Vol. 20, no. 8, August 1966

Methods of Automatic Program Changing for a Program-Controlled Automatic Office, *N. S. Bagrintseva, V. E. Valyuzhenich*—The paper describes a number of alternatives for adding to or modifying programs stored in a ferrite core memory which control an electronic central office. The use of a changeable program store facilitates writing program changes into another portion of the memory which may be dedicated to this function, or overwriting existing programs. The authors conclude that a separate memory is best for this purpose.

Practices such as described have been employed in the correction of errors in programs of other electronic switching systems.—*A. E. Joel, Jr.*

Part II—Radio Engineering

Vol. 21, no. 8, August 1966

Noise Immunity of a Diversity Reception Methods, *L. M. Fink, I. S. Andronov*—Optimum diversity receivers for Rayleigh and Rice (nonzero-mean) fading channels use weighted combinations of the squared outputs of matched-filter, envelope detectors. However, equal-weight combining is often used because it does not require explicit knowledge of the system parameters. In this paper, the loss incurred by this suboptimum procedure is estimated for different operating conditions. In most situations of practical interest the loss is less than 1 dB. The methods of analysis are fairly standard. Similar results obtained earlier by Pierce, Stein, and Turin in the United States and Kloosky in the U.S.S.R. are referenced, but not the more recent work of Bello and Nelin and W. C. Lindsey (published in the IEEE TRANSACTIONS ON INFORMATION THEORY and COMMUNICATION TECHNOLOGY). A new result in this paper is a closed-form expression for linear envelope combining of Rayleigh-faded signals.—*Thomas Kailath* analyzing the massive amounts of data, on-line computers were applied, using the counter-hodoscope technique. This technique allows 10^{12} electronic counter combinations to gather several million events (interactions) per hour.

Australian group issues a new electrical standard

The Standards Association of Australia, through its Committee on Industrial Switchgear and Controlgear, has published an Australian standard specification for direct-on-line ac motor starters for industrial use.

Issued as Australian Standard C364, the new standard has been largely based on corresponding recommendations of the International Electrotechnical Commission aimed at facilitating international trade in electrical materials and equipment. It applies to starters for circuits up to 11 kV and which are intended to start and accelerate a motor to normal speed and to provide means for the protection of the motor and its associated circuits against overloads.

Copies of AS C364 are now available from the various offices of the Standards Association of Australia (in Sydney, Melbourne, Adelaide, Hobart, Brisbane, Perth, and Newcastle). The price is $1.20 per copy.

Laser safety will be subject of January meeting

In an effort to evaluate laser safety programs, a Conference on Laser Safety has been planned for January 29–31, 1968, in Cincinnati, Ohio. The program will include not only seminars, but also actual laboratory exercises.

The Medical Laser Laboratory of The Children's Hospital Research Foundation of the Medical Center of the University of Cincinnati, together with the United States Public Health Service, Bureau of Disease Prevention and Environmental Control, National Center for Urban and Industrial Health, Occupational Health Program, and the Department of Environmental Health of the University of Cincinnati College of Medicine, will act as sponsors for the conference.

Further information is available from Mrs. Meredith S. Runck, Office Manager, Laser Laboratory, The Children's Hospital Research Foundation, Elland Avenue and Bethesda, Cincinnati, Ohio 45229.

Technical correspondence

Transportation by Triodyne?

I read with great interest the article "Electric cars—hope springs eternal" by Nilo Lindgren (see SPECTRUM, pp. 49-60, Apr. 1967). About 20 years ago I was working on such a vehicle. At that time, I had developed a versatile electric control system and one of the attempts to use it was as part of a hybrid electric automobile. Unfortunately for me, the interest in dc control systems began to wane because of the advent of static ac systems.

Although I tried other applications, I did not contact anyone concerning the automotive drive. The new interest in electric cars makes me think that there might be a place for my system at the present time.

Following is a short description of my device, which I call "Triodyne," and of the principle of the proposed car system.

The Triodyne principle

The Triodyne is a dc machine with three salient poles arranged 120° apart. Two independent electrical powers are connected to three brushes, also 120° apart.

The Triodyne works as a control device that coordinates a mechanical power with two electrical powers so that the algebraic sum of the three always is zero.

The principle is best illustrated by a few examples:

1. The Triodyne accepts a mechanical power input and delivers two electrical outputs.
2. The Triodyne accepts a mechanical and an electrical input and delivers an electrical output.
3. The Triodyne accepts an electrical input and delivers a mechanical and an electrical output.
4. The Triodyne accepts two electrical inputs and delivers a mechanical output.

Outside controls determine size and direction of two powers and the third power automatically adjusts itself to satisfy the basic equation

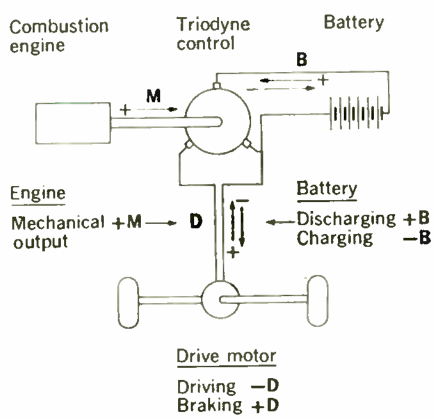
$$M + E_1 + E_2 = 0$$

where M is the mechanical power and E_1 and E_2 are the electrical powers.

The Triodyne is self-contained and always stable. It does not require outside stabilization auxiliaries as Pestarini's Metadyne does.

I had the opportunity to test the Triodyne principle in two applications:

1. One application was in a welding system with a constant dc input that the Triodyne converted into a welding power supply. Simultaneously, the Triodyne delivered mechanical power to its substantial cooling fan. The welding power output varied rapidly from open circuit to short circuit. The Triodyne followed these variations with fast response without changing its speed.
2. As a two-stage amplifier, the Triodyne was driven as a generator. The electrical input was used to excite the first electrical power, which then was used as excitation for the second electrical power that became the amplified output.



Basic equation: M + B + D = 0

	Motor	Battery	Drive	
M>D	Running(+)	Charging(−)	Driving(−)	B = M − D
M<D	Running(+)	Discharging(+)	Driving(−)	D = M + B
M = 0	Not Running	Discharging(+)	Driving(−)	D = B
Braking	Running(+)	Charging(−)	Generating(+)	B = M + D

(Efficiencies are disregarded)

The proposed Triodyne car

The Triodyne car is a hybrid electric vehicle with an auxiliary combustion engine. A battery supplies electric power to the drive motor (or motors). The combustion engine may be used on prolonged trips or for increased speed.

The Triodyne controls the power distribution between engine, battery, and drive motor as shown in the illustration. The driver controls only the drive motor. The demand of this motor establishes the flow of power. The Triodyne achieves this control merely with proper field coils on its three salient poles. No auxiliary devices and no black boxes are required. The combustion engine is not controlled and runs with constant speed and constant load tuned for optimum conditions.

Joseph M. Tyrner
Morristown, N.J.

Dissent welcomed

The June 1967 issue of IEEE SPECTRUM contained two items of great interest the letter (IEEE forum, page 11) by Mr. Ackerman concerning the question of editorial policy, and "Spectral lines" by C. C. Cutler, entitled "Duty to Dissent" (page 47). We observed with pleasure that the only reference made by Mr. Cutler to controversial material published by the IEEE was to an article that appeared in the pages of our TRANSACTIONS.

The IEEE TRANSACTIONS ON AEROSPACE AND ELECTRONIC SYSTEMS has always had an open invitation to all authors or prospective authors to submit sound material that presents an unpopular viewpoint. Just because we do not personally agree with viewpoints expressed in any material does not mean that we will not defend the individual's right to have his views made public. Our biggest problem in obtaining dissenting material has been in finding engineers and scientists who are willing to "record a dissenting opinion where the public interest is at stake." We will not, obviously, publish material of a "crank" nature, but will give fair "AES" time to those who make serious efforts to record their facts and opinions, and submit them to us.

When may we expect to receive the next articles of this type?

David B. Dobson
Executive Editor
IEEE TRANSACTIONS ON AES

Book reviews

Handbook of Military Infrared Technology, William L. Wolfe, ed.—*Office of Naval Research, Dept. of the Navy, Washington, D.C., 1965; 881 pages, illus., $3.75.* The word "military" might well have been omitted from the title of this handbook. It appears that the material covered is equally appropriate for use by any designer or systems engineer interested in infrared systems, regardless of the intended use. This book encompasses all that might be expected of such an effort, and more.

There are 22 chapters written by various experts in their fields. An extreme effort seems to have been expended in all but one chapter (on system design) to provide the latest data, techniques, and information. There is something of interest not only to the infrared specialist but also to the generally curious. For example, the six chapters dealing with optics (from component to spatial frequency filtering) will provide the reader with a surprising amount of information on other than infrared systems and components. The chapters on targets, backgrounds, and atmospheric phenomena gather together a tremendous amount of data, previously available but quite scattered throughout the literature, and place it at the fingertips of the reader. The chapters on spacecraft thermal design and aerodynamic influences on infrared system design provide information concerning some of the less familiar environments in which infrared systems must operate. The chapter on system design must, in the reviewer's opinion, be considered the weakest, although it could and should have been one of the strongest. The authors use expressions that are not verified to establish the operating constraints on various systems. Also, as opposed to the remainder of the handbook, there are no references in this chapter to other work.

There are a few other minor criticisms. On page 348 the symbol for complex index of refraction $\bar{\eta}$ is introduced without discussion. On page 380, Fig. 9-9 does not adequately represent or define the quantities discussed in the corresponding paragraph. On page 630, equation (15-88), the coefficient of the second term on the right-hand side of the expression is W_{40}, not W_{20}. On page 636, the seventh and eighth lines of paragraph 15.4.1 are garbled.

This handbook is recommended to not only the infrared systems designer but also to all others interested in the general field.

W. A. Miller
Radiometrics
Long Island City, N.Y.

Integrated Circuit Engineering—Basic Technology, G. R. Madland, *et al.*—*Boston Technical Publishers, Inc., Box 111, Cambridge, Mass., 1966; 391 pages, illus., $22.50.* This reviewer finds himself attempting to summarize a book which is itself a summary. Although undeniably a comprehensive, useful first reference book for the practicing engineer, the depth of coverage of integrated circuit technology in this book varies widely from section to section. The chapters are incomplete in themselves, and do not provide further references. The text has evolved from courses given by the Integrated Circuit Engineering Corp. staff, and the book is properly considered a handbook of integrated circuit technology. In this context, it fulfills a very necessary and important function.

The chapters treat the economic impact of integrated circuits, silicon integrated circuit materials and processes, integrated circuit design and testing (both linear and digital), and reliability and failure analysis. A great variety of data pertinent to these subject areas are given in the text and figures, although the obvious is often blended with the not so obvious. The data give the reader familiarity with a very broad spectrum of the subject, but do not provide the reader with competence to proceed much further.

For example, concerning integrated circuit resistor frequency response, it is duly noted that "the primary effect of parasitic capacitance on resistors is to limit their frequency response." This perfectly obvious notion is followed by an undocumented (and undemonstrated) equation for the resistor's cutoff frequency, which requires a background in distributed *RC* networks. This is followed by a table of typical resistor parasitics. Nothing is said of inductive parasitics, which might be significant in low-value thin-film resistors.

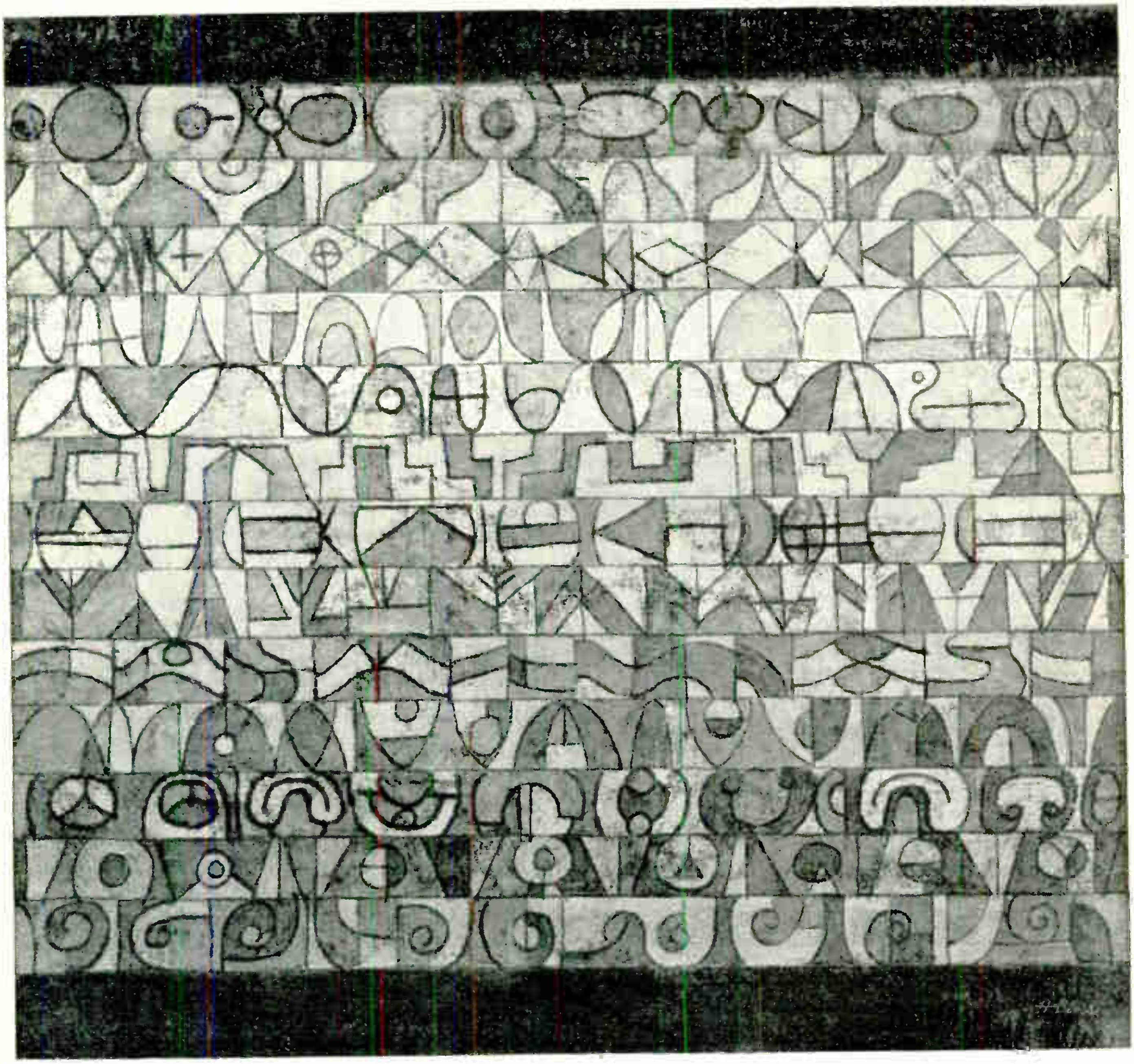
In retrospect, this (fourth edition of the) text, must be considered a handbook that requires extensive further reading for competence in the subject matter.

R. W. Wyndrum, Jr.
Bell Telephone Laboratories, Inc.
Murray Hill, N.J.

Introduction to Digital Electronics, Arthur W. Lo—*Addison-Wesley Publishing Co., Inc., Reading, Mass., 1967; 223 pages, illus., $10.75.* Professor Lo has drawn on over 15 years' experience at RCA Laboratories and at Princeton University to present in this little volume those facts and perspectives that are fundamental to an effective understanding of modern digital circuits. In a 35-page first chapter titled "Basic Concepts," the author introduces the fundamental ideas of quantization, physical representation of digital data, fan-in and fan-out, directivity and isolation (of circuits), basic logic circuit configurations, speed of operation, tolerances, design approximations, worst-case analysis, statistical analysis, and transients. The treatment of each topic is necessarily brief, but is in most cases excellently conceived and well carried out, as far as it goes.

Subsequent chapters are on transistor logic circuits (61 pages), cryoelectric and optoelectric circuits (20 pages), magnetic logic circuits (47 pages), logic circuits using negative-resistance switching elements, including parametrons and tunnel diodes (30 pages), and random access memories (28 pages). In each case the topics appear to be well chosen and succinctly introduced. The long chapter on transistor logic circuits includes sections on field-effect transistor logic circuits and integrated circuits, as well as good discussions of conventional bipolar transistor logic configurations and a fine introductory treatment of the bipolar transistor as a switching element.

Each chapter contains a bibliography, listed without comment. Unfortunately, no exercises or problems are given, thus reducing the appeal of the volume as a textbook. This lack, along with the conciseness of much of the writing, suggests that the audience for which the book is best adapted is perhaps those engineers or students who have ample maturity and expertise in their



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own specialty (which may be in the subject area of the book), and want, in concise form, an authoritative, up-to-date, and balanced presentation of the full sweep of modern digital electronics. The beginning student who in his insecurity needs every step explained twice will not find the book to his taste, unless he is in the hands of a good instructor who will help with the details and provide examples and exercises. For the mature reader, however, this work should provide an enriched perspective on a most important part of modern electrical engineering.

Howard E. Tompkins
University of Maryland
College Park, Md.

Electronic Theory of Heavily Doped Semiconductors, V. L. Bonch-Bruyevich—*American Elsevier Publishing Co., Inc., 52 Vanderbilt Ave., New York, N.Y., 1966; 124 pages, illus., $7.50.* This book, a translation from the Russian, summarizes the status of the theory of degenerate semiconductors at the time of writing (1965). Comprehension of the material requires a knowledge of second quantization, the many-body problem, and the Green's function method of solving equations. Among the topics treated, all briefly, are the Fermi level, static electrical conductivity and optical absorption in degenerate semiconductors, degenerate semiconductors with an incomplete homopolar lattice, and p-n junctions between degenerate semiconductors. The book contains an excellent bibliography covering both theoretical and experimental work in this area through 1965.

The volume is a good point of departure for a serious student of the important problem posed by heavily doped semiconductors, which are used in tunnel diodes, semiconductor lasers, thermoelectric devices, and thin-film devices. However, the reader needs to have a high degree of sophistication in solid-state physics to appreciate the presentation.

J. J. Loferski
Brown University
Providence, R.I.

Noise and Its Effect on Communication, Nelson M. Blachman—*McGraw-Hill Book Co., Inc., 330 W. 42 St., New York, N.Y., 1966; 205 pages, illus., $13.50.* The serious student wishing a good introduction to many of the aspects of statistical communication theory will find this little book of scarcely 200 pages well suited to his needs. A mathematical background consisting of basic concepts in probability and Fourier integrals, plus knowledge of some special functions mentioned in the text, would be required for independent study.

The author begins by introducing the multivariate normal distribution, and continues with a general chapter on random processes. A discussion of power spectra and their measurement, plus an interesting and enlightening discussion of some aspects of the spectra of angle-modulated waves, are highlights of the remainder of Part I, along with a discussion of the first two moments of the distribution of zero crossings for a Gaussian random process. As a by-product of this first division of the book, the author provides the reader with a good heuristic understanding of the meaning of ergodicity. Unfortunately, there does not seem to be any real attempt made to indicate why this is an important concept. Had Dr. Blachman done as excellent a job on this latter aspect as he did on the former, then this reviewer, at least, would be somewhat wiser on the subject.

Part II begins with a general method of describing the output of instantaneous nonlinear devices when the input is a (very) narrow-band signal. This is followed by a discussion of analog FM demodulation from the output signal-to-noise ratio viewpoint and the resulting interpretation in terms of "clicks." The final chapter of the section provides an introduction to optimum signal detection theory, and it is here that the author chooses to introduce sampling theory as well.

The book concludes with two chapters on information theory, including the concepts of channel capacity and the coding theorem.

The main fault of the book is stated by the author in the preface. A mathematically heuristic approach can lack conviction when unfamiliar concepts are being discussed. The principal virtue is a fresh, direct-to-the-point treatment of topics chosen as much for their practical as for their theoretical importance. In addition, the book contains many original and informative problems for the student.

J. E. Mazo
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Holmdel, N.J.

Designing Transistor I.F. Amplifiers, W. Th. H. Hetterscheid—*Springer-Verlag New York, Inc., 175 Fifth Ave.,* *New York, N.Y., 1966; 330 pages, illus., $12.00.* This book presents a systematic method for the design of transistor IF amplifiers for radio, television, and radar receivers. It is a useful reference book for electronic engineers and graduate students interested in circuit design.

Due to the internal feedback of transistors, the design of IF amplifiers is laborious. The author introduced a set of parameters, regeneration coefficient T and phase angle θ, to describe the overall feedback of the IF amplifier. With these parameters and a series of design charts, the performance of the amplifier may be found. A step-by-step design procedure as well as several complete examples are given.

The admittance parameters of transistors are used in all discussions. In chapter 4, a comprehensive discussion is given on the dependence of admittance parameters on bias, frequency, and temperature. Chapter 12 discusses the effects of spreads in these parameters. Three chapters are devoted to the survey of design theory, including discussions of stability, alignment, amplification, amplitude and delay response curves, neutralization, and AGC. However, this survey is a handbook-like summary. All details are omitted and referred to the author's other book, *Transistor Bandpass Amplifier* (referred to as Book I). Therefore, for complete understanding, these two books should be read simultaneously.

About one third of this volume is devoted to practical design examples, and another one third to normalized design charts. The examples are well chosen and design steps are easily understood, provided the reader will accept the results given in the theoretical survey. The lack of a more complete theoretical discussion and explanation of reasons for the approach as well as for the design charts may leave an inquisitive reader frustrated, even though reference is made to the author's other book.

This book is clearly written and concise. It is comprehensive in collecting the necessary information for the specific goal. As a whole, it is a useful reference book, and is recommended for electronic circuit designers as well as for graduate students.

W. H. Ko
Case Institute of Technology
Cleveland, Ohio

Dictionary of Electrotechnology: German–English, Eduard Höhn—*Chapman*

1967 IEEE INTERNATIONAL CONVENTION DIGEST AND RECORD

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and Hall, Great Britain; distributed exclusively in the U.S. by Barnes & Noble, Inc., 105 Fifth Ave., New York, N.Y., 1967; 705 pages, $22.50. This rather large dictionary of German terms in electrical technology should be of value to anyone seriously interested in translating German engineering literature. The dictionary is definitely a special-purpose work, and includes almost no terms from the general language. Thus, it supplements, rather than replaces, a more general work, such as that of De Vries (*German–English Science Dictionary*, McGraw-Hill, 1946). In addition, "electrical" technology is to be interpreted in the strict sense of electrical engineering, as contrasted with electronics, modern control theory, the computer sciences, etc. No attempt is made to include terms from these other areas.

Within the limits of power engineering, industrial processes, and the other classical areas of electrical engineering, the dictionary is admirably broad and complete, and stands as something of a monument to the German compound noun. (We are informed, for example, that a "Mehrphasenreihenschlussmotor" is a polyphase series commutator motor. This is symptomatic of a style of German technical writing that seems to be persisting in the areas covered by the dictionary.) The meanings of many of these compounds differ somewhat from the sums of their parts, and this dictionary is of real service in providing an exceptionally large number of entries, and what are obviously authoritative translations. The size of the work is comparable to the larger De Vries, i.e., DeVries and Herrmann, *German–English Technical and Engineering Dictionary*, 2nd ed., McGraw-Hill, 1966, but the coverage, being narrower, is a good bit more thorough. The breadth of coverage mentioned refers to the fact that many peripheral terms from law, economics, labor relations, production management, etc., are included.

The dictionary is generally well arranged and easy to use. Umlauted vowels are alphabetized, as, for example, "ae," which this reviewer found hard to get used to, and no genders are indicated anywhere, but no serious faults are evident. In short, this is a well-assembled dictionary that merits the serious consideration of anyone translating in the area of industrial electrical processes.

R. N. McDonough
Bell Telephone Laboratories, Inc.
Whippany, N.J.

New Library Books

The books described below were recently acquired by the Engineering Societies Library. Members of the IEEE in Canada and the continental United States may borrow books from the library by mail. The books may be kept up to two weeks; a charge of fifty cents for a week or a fraction thereof is made for each volume, exclusive of transit time. Requests for books and for information on literature searches, translation services, and photocopying and microfilming of library materials should be addressed to the Engineering Societies Library, 345 East 47 Street, New York, N.Y. 10017.

Advances in Materials Research; vol. 1: Experimental Methods of Materials Research, Herbert Herman, ed.—*Interscience Publishers, 605 Third Ave., New York, N.Y., 1967; 316 pages, $14.95.* This is the first volume in a series intended to serve as a "forum" for up-to-date accounts of progress, both theoretical and experimental, in the form of comprehensive and critical review articles. These critical evaluations of significant experimental techniques will be provided, in so far as possible, by men who contributed prominently to the development of these techniques. Four papers directly concerned with metals research are preceded by thorough treatments of X-ray and neutron diffraction, electron and field-emission microscopy, and electron-probe microanalysis.

An Introduction to Astrodynamics (2nd ed.), Robert M. L. Baker, Jr., and Maud W. Makemson—*Academic Press Inc., 111 Fifth Ave., New York, N.Y., 1967; 439 pages, 94s.* This is an undergraduate text that relates the theory and techniques of celestial mechanics to contemporary space-vehicle problems. Chapters 1 to 4 provide discussion of general laws, the minor planets and the moon, comets and meteorites, space geometry, and the principal coordinate systems. The nature and use of astrodynamic constants are next considered, followed by an extended treatment of observation theory, including electronic observations such as pulsed radar, phase shift, laser, and radio interferometer. Detailed applications to more advanced topics such as orbit determination and computation are to be covered in a companion volume.

Electronic Automatic Control Devices, A. A. Bulgakov—*Pergamon Press, Inc., 44-01 21 St., Long Island City, N.Y.,* *1966; 549 pages, $18.50.* This translation of a Russian book published in 1958 deals with electronic devices for automatic control and regulation of industrial plants and technological processes. A considerable section of the book deals with the theory, design, and practical application of the thyratron rectifier and inverter. Typical examples of the application of electronic devices to control units as used in various branches of industry are dealt with in the remaining chapters. Although mainly concerned with vacuum-tube equipment, the author has provided an introduction in this edition that deals with solid-state devices and relates them to the relevant chapters.

Engineering at Cambridge University; 1783–1965, T. J. N. Hilken—*Cambridge University Press, 32 East 57 St., New York, N.Y., 1967; 277 pages, $8.50.* This book recounts the history of a major university engineering school and the story of the acceptance of engineering as a valid university discipline. Starting at the end of the 18th century as a professor's hobby, engineering gradually came to be accepted, first as a part of a liberal education for men reading for the Ordinary Degree, and later as a fully fledged subject for university teaching and research. As of 1965 about 10 percent of all undergraduates were reading the subject, and a strong graduate school has also been established with over 150 research students. The history is interwoven with the biographies of the several eminent men who had much to do with its continuing development.

Engineering Electronics with Industrial Applications and Control (2nd ed.), John D. Ryder—*McGraw-Hill Book Co., Inc., 330 West 42 St., New York, N.Y., 1967; 690 pages, $12.50.* This text attempts to cover much of the basic device and circuit knowledge needed by those expecting to work in the control, computation, and instrumentation fields of electronic application. Broad principles are emphasized and illustrated, rather than details of specialized applications. The first two chapters provide a survey of electronic principles and vacuum and solid-state devices for those without previous training. Solid-state elements and principles are emphasized, leaving to the tube only those applications where it still retains some importance.

Gallium Arsenide (Conference Series No. 3), *The Institute of Physics and Physical Society, 47 Belgrave Sq., London S.W.1, England, 1966; 247 pages, $12.00.* This symposium, held at Reading University in September 1966, was organized in response to the rapidly increasing importance of gallium arsenide in a wide range of semiconductor applications, and was devoted to the technologies of material preparation and device fabrication. The 35 papers included in this volume fall within the following categories: materials preparation, including epitaxial techniques and growth from the melt; optical effects, with discussions of high-power lasers, radiation efficiency, and photoluminescence and degradation; microwave devices, such as mixer and varactor diodes and Gunn effect devices; and junction devices—transistors and diodes. Much of the interest derives from the fact that the wide band gap and high electron mobility extend the range of operation of gallium arsenide devices to high temperatures and high frequencies.

Gas Lasers, Charles G. B. Garrett—*McGraw-Hill Book Co., Inc., 330 West 42 St., New York, N.Y., 1967; 144 pages, $10.95.* Beginning with a brief historical introduction, the book continues with a discussion of gaseous amplifying media and optical cavities and the way in which they interact. Mechanisms of specific laser systems are then discussed: helium-neon, argon ion, carbon dioxide, and far infrared. An account is then given of the techniques involved in constructing a gas laser, with a description of the properties of the emerging laser beam as to power output, directional distribution, and phase and amplitude fluctuations. Other topics covered are the effects of intracavity modulation, frequency and amplitude stabilization, Q switching, and the application of magnetic fields.

Laplace Transforms for Electronic Engineers, James G. Holbrook—*Pergamon Press, Inc., 44-01 21 St., Long Island City, N.Y., 1966; 347 pages, $10.00.* This self-teacher for practicing electronics engineers requires a knowledge of differential and integral calculus and graduate circuit analysis. It is designed to give a thorough, practical treatment of the Laplace transform theory, enabling complete analysis of electronic network problems. Avoiding the abstract terminology of pure mathematics, the author devotes his first chapter to a review of complex variable theory as applicable to the Laplace transform, necessary to the derivation of the Laplace integral. The remainder of the book develops the theory and demonstrates applications to amplifiers, oscillators, passive and active wave filters, and other circuit elements. The revised edition contains much new material and a special chapter on the synthesis of transfer functions by models.

Modern Nonlinear Equations, Thomas L. Satty—*McGraw-Hill Book Co., Inc., 330 W. 42 St., New York, N.Y., 1967; 473 pages, $15.50.* An unusual coverage of material on seven types of equations is presented here. Operator equations, functional equations, difference equations, delay-differential equations, integral equations, integro-differential equations, and stochastic differential equations are all discussed. From the theoretical standpoint, this book provides a perspective of the field, discusses new techniques from the literature, and outlines recent developments. From the applied standpoint, it will help in developing new models for formulating problems and will provide a variety of existing types of equations, as well as some methods for their solution.

Probability in Communication Engineering, Petr Beckmann—*Harcourt, Brace & World, Inc., 757 Third Ave., New York, N.Y., 1967; 511 pages, $13.75.* This book has been written for students with little or no background in probability who want to study information theory, noise theory, reliability theory, or other branches of communication engineering in which probabilistic methods are applied. The elements of probability theory are first treated very thoroughly, as a common background to the other four parts of the book. These are on random phasor sums, random processes and noise, information theory, and reliability theory, and they may be studied in any desired sequence. A further practical aspect is provided by the wealth of applications to many problems—from signal detection and channel coding to preventive maintenance.

Residue Arithmetic and Its Applications to Computer Technology, Nicholas S. Szabó and Richard I. Tanaka—*McGraw-Hill Book Co., Inc., 330 West 42 St., New York, N.Y., 1967; 236 pages, $12.50.* The major objectives of this book are to provide a tutorial description of the basic principles and the shortcomings of residue (modular) arithmetic, to summarize comprehensively all published work in the field, and to describe several of its applications to computer technology. Chapters are devoted to discussion of number systems in general, the algebra and fundamental theorems of the residue number system, residue arithmetic operations, scaling and general division, overflow detection, and methods for representing and processing residue digits—including specific hardware techniques. Other topics covered include the problem of processing groups of digits, residue computing systems, conversion between digital residue numbers and analog variables, error checking, and checking binary systems and residue operations. A seven-page bibliography is included.

Scientists in Organizations, Donald C. Pelz and Frank M. Andrews—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y., 1966; 318 pages, $10.00.* Of interest to both scientists and engineers, as well as to administrators of research and development, this study examines the relationship between a scientist's performance and the organization of his laboratory. Questionnaires were submitted to scientists, professors, and engineers in a large midwestern university, five industrial laboratories, and five government laboratories. The book describes the method of the survey, and then proceeds to describe the analyzed results under the following subjects: freedom, communication, diversity, dedication, motivations, satisfaction, similarity, creativity, age, age and "climate," coordination, and group performance.

Switching Circuits for Engineers (2nd ed.), Mitchell P. Marcus—*Prentice-Hall, Inc., Englewood Cliffs, N.J., 1967; 338 pages.* This is a standard text covering the design and simplification of combinational and sequential switching circuits, with heavy emphasis on the practical rather than the abstract. Almost 50 percent of the book is on sequential circuits, and an original method is given for obtaining flip-flop excitation expressions in the synthesis of pulse input sequential circuits. Other topics discussed are logical circuits, electronic logic blocks, contact networks, tabular and map method of simplification, reiterative networks, and codes and error detection and correction. In the new edition the tabular method has been extended to multioutput networks.

The Engineer and His Profession, John Dustin Kemper—*Holt, Rinehart and Winston, Inc., 383 Madison Ave., New York, N.Y., 1967; 248 pages, $4.95 pprbk.* Primarily intended for students preparing to become engineers and for those who have recently entered the profession, this book attempts to capture some of the feel and vitality of what it is like to be in engineering. The aspects of engineering that are treated in the most detail are those of research, design, and development, as carried out in an industrial environment, together with related management activities. Also included are such subjects as salaries, patents, ethics, societies, registration, unions, and continuing education.

Recent Books

Advanced Studies in Electrical Power System Design, R. A. Hore—*Barnes and Noble, Inc., 105 Fifth Ave., New York, N.Y.,* $12.50

Algebre de Boole et Machines Logiques, J. Kuntzmann and P. Naslin—*Dunod, Editeur, 92, Rue Bonaparte, Paris 6ᵉ, France,* 78 F (approx. $15.76)

A Manager's Guide to Computer Processing, Roger L. Sisson and Richard G. Canning—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y.,* $6.95

An Introduction to the Electron Theory of Solids, John Stringer—*Review Dept., Pergamon Press, Inc., 44-01 21 St., Long Island City, N.Y.,* $6.00; $4.50 flexicover

An Introduction to Tensor Calculus and Relativity, Derek F. Lawden—*Barnes and Noble, Inc., 105 Fifth Ave., New York, N.Y.,* $4.50; $2.85 pprbk.

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