VOLUME 4 □ NUMBER 12 DECEMBER 1967

IEEE spectrum

features

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

departments

the cover

The fast Fourier transform has become a useful computational tool that facilitates many types of analysis by means of digital computers. This month's cover shows a typical tree-graph configuration of the FFT, as described in an article beginning on page 63 of this issue.

VOLUME 4 □ NUMBER 12 IEEE spectrum DECEMBER 1967

Spectral lines

Engineering and art. It is high time that someone refuted the notion that art and engineering are antithetical. Too often I have heard it said that engineering is cold and unfeeling, or even depressing; that the engineer with his slide rule and transit, his concrete and steel, or his wires and electrons does not appreciate the "finer things"; that his works are without aesthetic value.

Could it be that the authors of such remarks lack a comprehension of some of the most beautiful and moving elements of human experience? Surely, they do not understand the forces that motivate most of us, or appreciate the pervasiveness of art. They do not like what they do not understand.

I have never found a widely accepted definition of art. If we believe that "art is creation for (aesthetic) satisfaction," or "the application of ingenuity to the manipulation of emotion," or "systematic application of knowledge or skill in affecting a desired result," or "application of skill or taste to production according to aesthetic principles" (Webster), we admit the greater part of creative experience and must include our own creations. Indeed, are we not surrounded with examples of engineering that stand out as some of man's most aesthetic creations—the Golden Gate Bridge, the Eiffel Tower, the F-11 jet, or the 1903 Oldsmobile? Some of the best examples of modern art are created in our own field. Have you ever looked closely at a thin-film integrated circuit or a thyratron in action?

But man's most beautiful creations are not physical. They are to be found in the conception of ideas. What is more beautiful than some of our basic scientific or engineering relationships? Here is simplicity, symmetry, variety, contrast, order, and an element of surprise. And what of the concepts of resonance, harmonic analysis, with overtones in quantum mechanics almost beyond human comprehension? As in other branches of art, pleasure is found in the synthesis of such ideas in the creation of new and exciting combinations. What can have more aesthetic value than the appreciation of general principles that are timeless and universal? The catenary is more beautiful than the bridge; the logarithm than the tower; Newton's third law than the jet. We share a problem with great artists in that the beauty and significance of great engineering, scientific, and mathematical works are not widely appreciated. No one who has not mastered the basic disciplines of science is qualified to judge the aesthetic value of our work.

The artist and the scientist or engineer have much in common in their very nature. Many of our leaders are not bad amateur painters, musicians, and sculptors, even without training. Although few have prospered, as did Leonardo da Vinci, as both artist and engineer, it is clear that for many a fundamental choice of profession was made very early in life and through rather subtle influences. In many cases, the basic difference is in concentration of effort. We agree with Spengler[1] that: "Newton, Gauss, and Riemann were artist-natures, and we know with what suddenness their great conception came upon them."

Under slightly different social conditions might not many of us have ended up in the arts, and conversely? Are not the great peaks of productivity in the arts and sciences perhaps caused by the attraction of the most gifted people to the areas in which such advances are made? In recent years there have been unprecedented forces encouraging gifted youth into the sciences. Probably many potentially great artists today are creating new physical theories, or building jet engines.

Great art is often not recognized as such by the generation that produces it. Perhaps we are living in the midst of what will eventually be seen as the best example of this, an artistic renaissance in the form of engineering.

It is difficult to find examples of modern art produced by premeditation that can excel the sometimes accidental output of our machines and laboratories. The best example of junk art I have seen was an experimental transistor amplifier with uncut pigtails and no breadboard, which an engineer had tacked to his door because it was "pretty." The computer has produced random patterns more Mondrian than Mondrian's own work.[2]

We can take some satisfaction in recent efforts to promote collaboration between artists and engineers, and between artists and digital computers. Artists have always worked with the tools of applied science, else they would be without paint, chisels, or strings. It is high time they learned to use electronics and power more effectively in their creations, whereas engineers undoubtedly can profit from the artistic viewpoint. Collaboration is common in the popular arts, in the mass market of publishing and entertainment, styling and architecture. Unfortunately, excellence in art has not often survived the relationship. Collaboration of engineers with the purveyors of "fine art" and "modern art" will be really productive only if we match excellence with competence. The problem doubtless is one of communication between such diverse points of view. Let us hope that some can successfully bridge the gap. The artist who profits most therefrom will have become an engineer.

We build with solid stuff but our works are not less aesthetic because they are useful. Let us apologize to no one. Engineering is nobility in art.—*C. C. Cutler*

REFERENCES

1. Spengler, O., " Meaning of numbers" in *The World of Mathematics*. New York: Simon and Shuster, vol. 4, p. 2315.
2. Noll, A. M., "The digital computer as a creative medium," *IEEE Spectrum*, vol. 4, pp. 89–95, Oct. 1967.

Authors

Data communication requirements of computer systems (page 42)

John C. McPherson (SM), vice president, International Business Machines Corporation, Armonk, N.Y., joined the company in 1930 as a sales representative and, three years later, was named assistant manager in the Railroad Department. He subsequently held posts as manager of the Future Demands Department, director of Engineering, and manager of Patent Research and Development.

In 1948 Mr. McPherson was elected to the post of vice president at IBM and, 12 years later, he was named director of the IBM Systems Research Institute. He organized the Special Systems and Equipment Department in 1965 and, currently, is engaged in advanced computer and programming studies.

An electrical engineering graduate of Princeton University, he has served as chairman of the Advisory Council of the Department of Electrical Engineering at Princeton and as a member of the university's Graduate Council. He has acted as a consultant to the U.S. Assistant Secretary of Defense (R & D) and is a member of the Executive Committee of the Advisory Council for the Advancement of Industrial Research and Development of the State of New York.

World War II: Electronics and the U.S. Navy Magnetic mines, acoustical and homing torpedoes, and proximity fuzes (page 46)

Gordon D. Friedlander. A biographical sketch of Mr. Friedlander appears on page 111 of the February 1965 issue.

Electrogasdynamic energy conversion (page 57)

Edward M. Walsh (M) is presently director of the Virginia Polytechnic Institute Energy Research Group and he has been a member of the school's electrical engineering faculty since 1965. He received the B.E. degree from the National University of Ireland and both the M.S. degree in nuclear engineering and the Ph.D. degree in electrical engineering from the Iowa State University.

As a member of the staff of the Iowa Power and Light Company, he developed the "learning-curve technique" for long-range nuclear power cost prediction. He was appointed to the post of assistant professor of electrical engineering at Iowa State at the age of 24.

Dr. Walsh is the author of the recently published textbook, *Energy Conversion, Electromechanical, Direct, Nuclear*, and of ten published papers on nuclear power, direct energy conversion, and engineering education. He is a member of the American Nuclear Society.

The fast Fourier transform (page 63)

E. O. Brigham (left) directs research in signal processing and analysis, digital filtering, learning systems, and related areas at LTV Electrosystems, Inc., Greenville, Tex. Between 1964 and 1967 he served as an instructor at the University of Texas and conducted research in the application of inverse digital filters to signal restoration. The same school awarded him the B.S.E.E., M.S.E.E., and Ph.D. degrees, in 1963, 1964, and 1967, and he is a member of Eta Kappa Nu, Tau Beta Pi, and Phi Eta Sigma.

R. E. Morrow (M) is group supervisor of the Electronic Sciences Research Group for LTV Electrosystems, Inc., and a visiting industrial assistant professor of electrical engineering at Southern Methodist University Institute of Technology. From 1957 to 1961 he was a field representative on airborne radar and weapons control systems for Hughes Aircraft Company and, in 1964–66 was an assistant professor of electrical engineering at the University of Mississippi.

Cooperation of universities and utilities for the education of power-system engineers (page 71)

E. A. Erdelyi (F) (left) directs graduate and undergraduate courses in electric power in the Department of Electrical Engineering and also several research contracts for the University of Colorado. He holds the Dipl. Math. degree from the Masaryk University, Brno, Czechoslovakia, and the Ph.D. degree from the University of Michigan. He has served as a professor of electrical engineering at Syracuse University and as H. Rodney Sharp Professor at the University of Delaware.

F. S. Barnes (M) is professor and chairman of the Department of Electrical Engineering at the University of Colorado, and he is a consultant to the National Bureau of Standards in the area of physics. He was awarded the Ph.D. degree from Stanford University and, during the last year of graduate study, was a Fulbright professor at the College of Engineering, Baghdad, Iraq. He was a research associate with the Colorado Research Corporation (1958–59) prior to joining the Colorado faculty, and he is the recipient of the ASEE McGraw-Hill Research Award.

Today's need for balanced urban transit systems (page 87)

Edward L. Michaels (SM) joined the University of Houston, Tex., in 1960 as professor and chairman of the Department of Electrical Engineering. He was responsible for the establishment of the department's Ph.D. program (1963) and during 1965–66 he was a visiting Fulbright professor at Finland Institute of Technology. Currently, in addition to his duties as professor at Houston, he is doing research on a NASA study contract on new methods of multiplexing and deep-space television, and he is writing a textbook on engineering systems analysis.

The author of 40 technical reports and published papers on systems analysis, display systems, and mass transportation systems, he has, during the summers between 1961 and 1965, done research for Texas Instruments, Esso Production Research Company, and for the SIE Division of Dresser Electronics; he also has participated in the Ford Foundation Computer Programming Institute at the University of Michigan.

"IEEE Headquarters"—people, facilities, and functions (page 92)

Donald G. Fink (F), prior to joining IEEE in 1963 as General Manager, was vice president for Research with the Philco Corporation and Director of the Philco Scientific Laboratory. He has also served as editor-in-chief of *Electronics* (1946–52), as an expert consultant on radio, navigation, and radar in the Office of the Secretary of War, and as head of the Loran Division at the M.I.T. Radiation Laboratory (1943).

A Fellow of both the AIEE and the IRE, he served as IRE President in 1958. Also, he is a Fellow of SMPTE and the IEE (London), an Eminent Member of Eta Kappa Nu, and a member of Tau Beta Pi and Sigma Xi. He has authored or served as editor for many books in the fields of electronics, television, and radar, and is editor-in-chief of the forthcoming tenth edition of the *Standard Handbook for Electrical Engineers*. His honors include the Medal of Freedom (1948), the Presidential Certificate of Merit, the IRE Radio Fall Meeting Plaque (1951), and the American Technologist Award.

Conference on Electron Device Research: A pattern to be copied? (page 100)

Charles Süsskind (F) is professor of engineering science and assistant dean in the College of Engineering of the University of California at Berkeley. Prior to joining the Berkeley faculty in 1955, he was a research associate and lecturer at Stanford University for four years. He is the coauthor of *Fundamentals of Microwave Electronics* and editor of *The Encyclopedia of Electronics*. At the present time, he is engaged in research on a book-length history of radar under a National Science Foundation Grant.

Dr. Süsskind served with the U.S. Air Force (1942–45) and then attended the California Institute of Technology, receiving, in 1948, the B.S. degree. Three years later he was awarded the Ph.D. degree from Yale University. He has contributed extensively to the research literature in several fields, particularly in the areas of electron optics and bioelectronics.

Data communication requirements of computer systems

The growing field of teleprocessing—the use of one or more central computers by many distant substations—is placing new requirements and burdens on communications technology, so that intercomputer communication speeds can be accelerated

John C. McPherson

International Business Machines Corporation

Teleprocessing systems are mushrooming throughout public and private industry: computer-to-computer links form an integral part of our national defense system and air traffic control; manned terminal-to-computer systems establish reservations on airlines and at motels; hybrid systems keep our tax returns honest. But these computer centers, remote terminals, and displays are often far apart, and require lines of direct communication. A large number of inexpensive, switchable data channels are needed, with a speed resolution of 10 to 20 characters per second, for connecting human-operated terminals to a multiplex of special-purpose computers. Machine-to-machine communication requires channels with high-speed data resolution that are several orders of magnitude faster, with virtually error-free performance.

The area in which data communication and computer systems in combination furnish a useful service is rapidly growing, and there are indications of a much greater growth in the future. In essence, given a suitable data communication network, a particular computer can serve a large number of dispersed terminals, and—more significantly—an individual, at his terminal, can make use of any one of a number of computers for specialized information or services.

In the two technologies concerned, recent progress has permitted revolutionary changes in methodology.

When technology shows a way of improving performance by a factor of ten or more, major changes in our civilization usually follow. In computer technology, costs of some individual electronic components have decreased by a factor of more than 1000, with corresponding reductions in size in the last two decades. Prices of integrated circuits have been reduced by a factor of ten the last few years; moreover, performance has improved dramatically.

Improvements also have been striking in communication technology. Long-haul telephone channels, which cost $200 per channel mile 30 years ago, now cost somewhere between $10 and $20, a reduction factor of more than ten. Coupled with this improvement is an expansion in bandwidth by a factor of ten or more. In addition, the introduction of digital transmission systems has made it possible to increase the data transmission capacity of voice circuits by a factor of roughly 25 over analog voice channels.

The development of digital transmission methods has made it possible to transmit a very large number of channels over a pair of wires. A telegraph channel on the switched network operates at 150 bits/s. The line rate of the T1 carrier system is 1 544 000 bits/s; and this repeatered line could transmit approximately 10^4 telegraph-speed data channels.

Thus the technological base for what is called teleprocessing—the use of computers at a distance—is one of high-capacity and low-cost data communication facilities, particularly where large bandwidths are involved, and high-performance, low-cost computing systems specialized to simplify their direct use by the customer.

Remote data-processing systems

A number of remote data-processing systems are emerging with distinct characteristics and communication requirements. For purposes of discussion, they are grouped as inquiry systems; data-collection systems; conversational computing systems; remote batch-processing systems; information distribution systems; interactive graphic systems; and remote document-production systems.

Inquiry systems, typified by the airlines reservations systems, connect a large number of terminals to a single data-processing center, and serve to keep track of a particular facility on a total system basis. Other inquiry systems include hotel reservation systems and centralized inventory-control systems. One under study is a mechanized telephone directory information service.

Data-collection systems are typified by the various weather reporting systems, the reporting of transactions on the stock exchange, and, within companies, the reporting, from many terminals, of the status of factory production.

Conversational computing systems, including time sharing in the strict sense of the term, are now proliferating rapidly. These systems share a computer's time among a group of users, at terminals permitting them to enter programs a statement at a time and carry out calculations on the computer, using the facilities of a large program library provided in the central system to facilitate their work. Conversational computing systems include Quiktran, the Administrative Terminal System, and Datatext, for storing text material for revision or updating. The potential variety of services offered by these conversational computing systems appear almost unlimited, since computing systems can be tailored to a wide range of specialized needs.

A very promising conversational-system use is computer-aided instruction, where students at individual terminals study computer-assigned material, answer computer-posed questions, and perform assignments on the terminal. Work can be immediately corrected by the computer and used to guide the future course of instruction.

Remote batch-processing systems are somewhat similar to conversational computing systems, but do not give the immediate response that is the essential characteristic of conversational systems. Large jobs may require transmission of large amounts of data and program; and, for this kind of work, batch processing is more efficient than line-by-line problem entry. In many instances, such systems will connect computers with one another for load balancing, or for the transfer of jobs checked out on a small computer to a larger and faster unit for production runs. Remote batch-processing systems are also used for increasing the reliability of a set of computing facilities by providing backup for one another, or to combine the work loads of two or more locations on a single large computer. It is anticipated that remote computing systems will be increasingly employed as a method for using computers on a per-hour or per-job basis, without requiring the man with a problem to go to a computer center.

Information distribution systems may very often operate like inquiry systems. In addition, distribution systems will broadcast information on a selective basis to customers. Stock quotation services, and the distribution of railroad freight traffic information to railroad traffic agents, shippers, and consignees, are examples of such systems now in operation. In the future, as technical information such as bibliographies, abstracts, and complete documents is accumulated in appropriate form, the distribution of information from the machine files, pertinent to specific inquiries, will take a central position in automated information retrieval systems, and will distribute technical know-how more directly than through the present media of publication. The computer affords a memory storage facility in a data communication network that is ready for exploitation. What is "said" now can be recalled automatically by any number of people at any later date. A direct inquiry-and-answer service—24 hours a day—could supplement publication and widespread distribution of timetables, telephone directories, city directories, classified directories, address lists, price books, stock lists, and similar documents.

Interactive graphic systems are in use for displaying computer-supplied information on a cathode-ray tube in response to inquiries from a terminal, and are being used on a local basis for the design of electric circuits and for displaying the dynamic response of such circuits, for the design of wiring patterns and printed circuits, for the formation of integrated circuit masks, for the design of three-dimensional structures such as ships' hulls, automobile bodies, airplanes, and for other computer-aided design activities. These systems also play an important part in the plans for computer-aided instruction, where pictures or drawings, in addition to text, either simplify the presentation of information or provide a more convenient method for student interaction and response to course material.

Remote document-production systems form a class of remote data processing that permits the use of a central computer to do the paper work for a large number of other locations in a manufacturing and marketing organization by producing the printed documents at the point of use. In addition to printing business documents at remote locations, the systems can also print graphical information, such as circuit diagrams, flow charts, line drawings, and specifications. This involves one-way transmission of very large amounts of digital information, as well as high-speed reproduction equipment associated with the remote terminal.

Systems in use

To show the extent to which these remote data-processing systems are already in use, IBM can be cited as an example. For a number of years the company has used a broadband, 48-kHz switched network to permit the interchange of computer information between main plants and principal remote locations. The system started out with a single line connecting computing centers in New York and Poughkeepsie, N.Y. Today it involves 30 terminals, receiving and transmitting computer data at the rate of 5100 eight-bit characters per second. These 30 points include locations as far away from the principal plants in Poughkeepsie and Endicott as Raleigh, N.C., Rochester, N.Y., San Jose and Los Angeles, Calif., and Chicago, Ill. There are approximately 22 500 broadband-circuit kilometers in this net. At present, the terminals are used on an average of 70 hours per month. All switching is via a broadband switch at White Plains, N.Y.

In addition, IBM has a very-high-speed data communication network, connecting some 60 small, stored-program test stations to a central computer and file system in one of its plants. This system is connected by an IBM-designed digital transmission system, working at a rate of 1.25 million bits per second, so that information can be delivered to any of the test stations from the central data bank at better than magnetic tape speeds. The network is used for manufacturing and test purposes in the plant, and avoids the cost of independent input devices such as cards, paper tape, or magnetic tape at the individual test stations. It also provides a manufacturing information collection system as well. Data communication circuits are up to 1.6 km in length. Additional types of terminals for data collection, process control, and data input to computers under test have been designed and added to the original system.

Two networks are used for communications between Poughkeepsie, field engineering support centers, and a number of branch offices. One permits terminals at the branches to be used for computer-assisted instruction in maintenance techniques. The other network is used to collect information concerning machine and program problems encountered in the field, and to provide immediate maintenance and programming corrections. At present, there are about 75 terminals connected via off-premise Centrex lines from the Poughkeepsie switchboard. This network will probably increase to about 250 inquiry points, and the communication facilities will be suitably rearranged. Inquiries concerning specific machines, and particular engineering or program change notices, are handled by the central computer, which replies with a typed message while the inquirer is on the line. Voice-grade lines on the telephone network are also utilized to provide temporary remote terminal access to several experimental computer systems at the IBM Research and Advanced Systems Laboratories.

For management information, IBM has terminals at each of ten district offices that communicate with a computer at the Marketing Division's headquarters in White Plains, N.Y.; the system supplies daily information on marketing activities and orders.

The Internal Teleprocessing System, the most frequently used network, has 56 400 km of teletypewriter-speed private lines, connecting terminals at some 300 locations within the United States, and 21 abroad, through a store-and-forward message center at Armonk, N.Y. The overseas terminals are connected over two voice-grade cable circuits to Europe and one telegraph-speed circuit to Tokyo. The system is currently handling a daily input of approximately 12 000 messages, each averaging approximately 350 characters. The system has provision for storing and retransmitting any message from the current or previous day from the message-switching center on request.

System requirements

The communication requirements for the wide variety of different data-processing systems seem to fall rather nicely into two basic types: one in which interaction with the machine is at human speeds, the other in which information is passed from machine to machine.

Where human interaction is involved, a speed of 10 to 20 characters per second is suitable; and a very large number of low-cost data channels is needed to connect inexpensive terminals to a multiplicity of computers, each offering a specialized service. Typically, inquiries and replies will be short, a matter of 20 to 50 characters.

The data channels will, for some applications, require long connection times, such as the duration of the period a terminal is working with a central computer. During this period, the channel will be in use only a small portion of the time. It will be idle while work is being carried on by the computer, and while the user is considering his next step. Other applications, involving simple inquiries, may only require connection times of a few seconds.

These channels need to be switchable. A terminal will need to be connected to different central computers to use particular programs that are permanently established in a particular machine, or different central reference files from which information is being requested. As such systems proliferate, a user may be transferred from the nearest special computer to a more distant one if his normal machine is currently loaded to capacity. This network will need, in view of the normal long period of time during which a connection is maintained, either a large number of data channels or some method of extremely fast switching for channel sharing to take care of fluctuations in the alignment of terminals and users.

For machine-to-machine communication, channels are needed that can transfer data at much faster rates than input speed. For transferring large files, even higher speeds may be necessary. The continuous transmission of 5000 characters per second, although fast in terms of normal record communication requirements, is slower, by a factor of 8 to 32 times, than computer input from tapes. However, such channels can transfer extraordinarily large amounts of information in the course of an hour's time. You might say it is in excess of the average need, but cannot meet the instantaneous requirements of computer-to-computer interaction. Again, these channels will normally work on a "burst" basis, with intervening periods when the channel is idle. Since the characteristics of a computer call for loading it with a relatively large amount of information—both data and programs—before it can start to do its work, lower speeds require more buffering before entry into the computer.

High-speed channels for processor-to-processor and processor-to-printer transmission need to be very nearly error-free. These channels will be used to transfer large masses of data and of programs from one place to another. Unless there can be complete assurance that the work is transferred to its destination exactly as it was at the origin location, the services of the remote computing system will not be satisfactory. Some means, not only for maintaining a good circuit, but for checking the correctness of the information transmitted, is essential.

Transmission requirements

In setting a criterion for transmission accuracy, error rates of the computers, with which the circuits are coupled, should be considered. Assuming the computer to be handling communication traffic consisting of bits moved locally, within itself, over short, almost noise-free lines, the error rate, based on time between errors in the central processing unit, is estimated to be of the order of one bit error in 5×10^{12} to 5×10^{13} bit operations. This is several orders of magnitude higher than present data communication standards.

Communication channels that approach machine speeds will be used not only for machine-to-machine communication, but also for links between computers and high-speed printers, and between computers and electronic display units. It would be desirable to switch high-speed channels as needed, as is done with lower-speed channels. It is also desirable to reduce connection set-up time for switching broadband lines. Much of the high-speed channel use will be for short periods of time on a demand or inquiry basis, where the amount of data to be transmitted is large and the total information is needed immediately. Much of this transmission will be periodic: daily, weekly, or monthly. Many potential applications exist that would not justify a dedicated channel between the computer source and the point of use.

Speeds approximating machine-to-machine communication rates are also necessary for the effective use of cathode-ray-tube displays. The usefulness of these devices is based on their ability to display quickly a line drawing or a page of information consisting of hundreds of characters. Present voice-line services (240 characters per second) reduce the native display terminal response speed by a factor of ten.

The widespread use of computers on a remote basis for inquiry-type operations can be greatly expanded if the low-speed data channel, and the terminal, represent a user cost of the order of his present telephone instrument. To achieve such an objective, the terminal apparatus and the line signal method should be chosen to help one another and to eliminate, to the greatest degree possible, terminal functions that add to its cost, by handling as much as possible with common electronic apparatus at the computer. For example, the same signaling system might be used both for making the connection and for the transmission of data.

Data network requirements present some real challenges to the communication switching system designer as some computers will be dialing terminals at high repetition rates, and using the resulting connection for periods of time comparable to that taken to make the connection, whereas other connections will be held for long periods of time.

A desirable feature of data networks would be a broadcast facility, such as using a single period of time to reach a large number of terminals at the same time with a common transmission. Good economics dictates that the terminals and line terminations at the computer either should be connected directly to the data channel, or should end in integral communication signaling generators and detectors, using the same housing and power supply as the terminal or the computer, and not a separate unit.

The potential increase in data communications bandwidth of several magnitudes, suggested by the improvement in digital communication technology, offers the designer of combined data processing–communication systems an opportunity to respecify the total package to reduce overall cost by using bandwidth to eliminate hardware, particularly in the terminals, and increase reliability and accuracy. It may be possible to take advantage of the large increases in bandwidth to establish standard transmission patterns of speed, character set, and format for the various types of terminal devices that can permit the widest possible interchange of data between points in the communications network.

The availability of a high-quality, inexpensive, switchable data communication network, in addition to contributing a lower cost in the communication element of the system, has important secondary effects on the cost of the total data-processing service. By making tributary areas for a single computer larger, it would suggest centralizing work on fewer, larger machines, with a decrease in the cost of maintaining both hardware and programs at a large number of locations to provide the equivalent service. For a given service, it is possible to couple the use of a program closely with its improvement, correct errors discovered, and initiate improvement in accordance with the needs of the user much more freely and promptly than is possible when the programs must pass through a comprehensive testing-and-release procedure for all-purpose use on a large number of machines.

Similarly, good data communications makes it feasible to undertake computer services based on big directories that require wide use to cover their costs of initial preparation and continuous updating. These big directories prove to be more useful than their smaller counterparts, by containing all of the information on a particular subject, or information of a particular kind.

To facilitate expansion of remote data processing, uniformity of signaling rates and character codes is desirable. Interaction between a terminal and a multiplicity of computing centers and information banks thus can be readily achieved. This is an area in which standardization clearly benefits the user by expanding the range of services that he can command. Standardization coupled with good, cheap communication would make it more practical for different computing installations to specialize in a particular application, or set of programs, and to provide a more efficient service than a general computing center, which would have to be prepared to furnish service on a number of applications simultaneously to different users. If all Fortran work is done on a given computer, it can provide a faster service by maintaining the Fortran compiler program in high-speed memory permanently, and applying it directly to each user's input stream as rapidly as it is received. This specialization benefits the user even more than the service supplier. If, from one terminal, he could reach and use any one of a dozen special programs in various computer centers, he would have at his command high-performance services that would surpass those that he could provide economically in a general-purpose installation of his own. Fluctuating volumes are always a problem, and perhaps can be met more effectively by intergrating the demands of a large number of customers and assigning additional computers, as necessary, to an application that becomes overloaded.

Another apparent advantage of a large number of terminals operating via communications channels to big computers is the improved access this could provide to large program libraries, while sparing the users the problem of acquiring and maintaining such libraries themselves. However, anyone familiar with the difficulties inherent in using someone else's program knows that supplying such programs is not a trivial problem. Hopefully, we can make progress in this area, since it holds the potential of being the biggest single help in making computers useful to the ordinary person. Optimally, the requirements on the user should be reduced to understanding the service offered and the rules for entering requests and data to get results, thus simplifying operations for all concerned.

One specific way has been presented in which data-processing and data communications technologies can be combined to the substantial benefit of the users. The object of this suggestion is widest possible availability of data-processing services of any kind, anywhere in the United States, to anyone who can afford a terminal.

Data processing, when backed up by efficient and economical communications, appears to have potential uses far beyond anything that has been indicated by current equipment using existing communications channels tailored for analog voice transmission. The present evolution and installation of digital transmission facilities holds the promise of making distant use of data-processing equipment nearly as effective as if the computer were in the same room.

The mutual stimulation—really a symbiosis—of digital computer and direct digital communication should expand the usefulness of data processing by a large factor, perhaps even the orders of magnitude required so that the computer can be of use not only to every business, but also to every individual.

BIBLOGRAPHY

Franklin, R. H., and Law, H. B., "Trends in digital communication," *IEEE Spectrum*, vol. 3, pp. 52–58, Nov. 1966.

Halina, J. W., "Data transmission—current trends and future prospects," *Elec. Commun.*, vol. 41, no. 2, pp. 177–195, 1966.

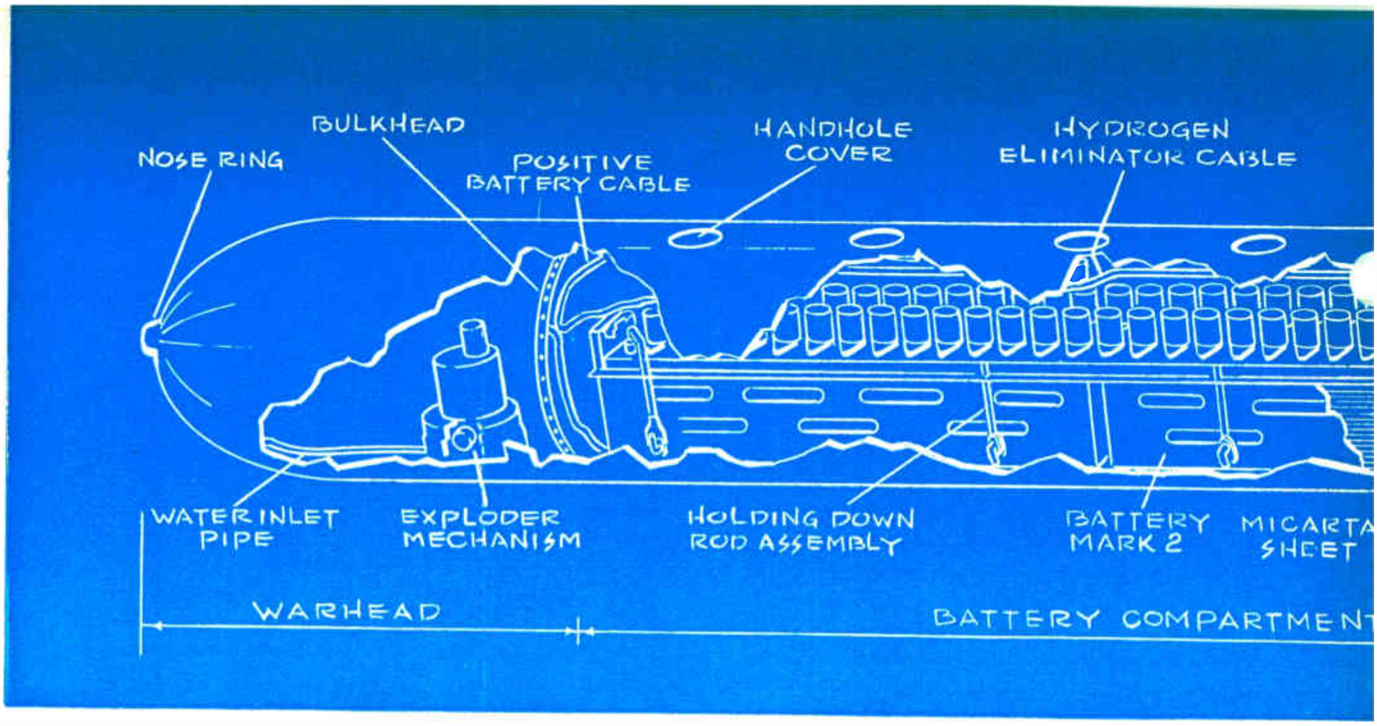
Hoth, D. F., "Digital communication," *Bell Lab. Record*, vol. 45, pp. 38–43, Feb. 1967.

James, R. T., "High-speed information channels," *IEEE Spectrum*, vol. 3, pp. 79–95, Apr. 1966.

Kelly, R. A., "Experimental high-speed digital transmission system," *Bell Lab. Record*, vol. 45, pp. 44–48, Feb. 1967.

Pierce, J. R., "New means of communication," *IEEE Spectrum*, vol. 3, pp. 62–65, Aug. 1966.

Stuehler, J. E., and Watkins, R. V., "A computer-operated manufacturing and test system," *IBM J. Res. Develop.*, vol. 11, pp. 452–460, July 1967.



World War II: Electronics

Magnetic mines, acoustical and homing torpedoes, and proximity fuzes

War is a killing game that is brought to its highest playing efficiency by the scientific researchers, engineers, and technicians of all major powers. Although some of the devices and techniques were developed in peacetime, the majority of the weapons systems were evolved in wartime crash programs, usually in response to new and advanced devices used by an enemy. Thus, with the advent of each new weapon, an equally important task had to be accomplished—that of finding an effective countermeasure.

Damn the torpedoes . . . full speed ahead!
—Admiral Farragut at Mobile Bay, 5 August 1864

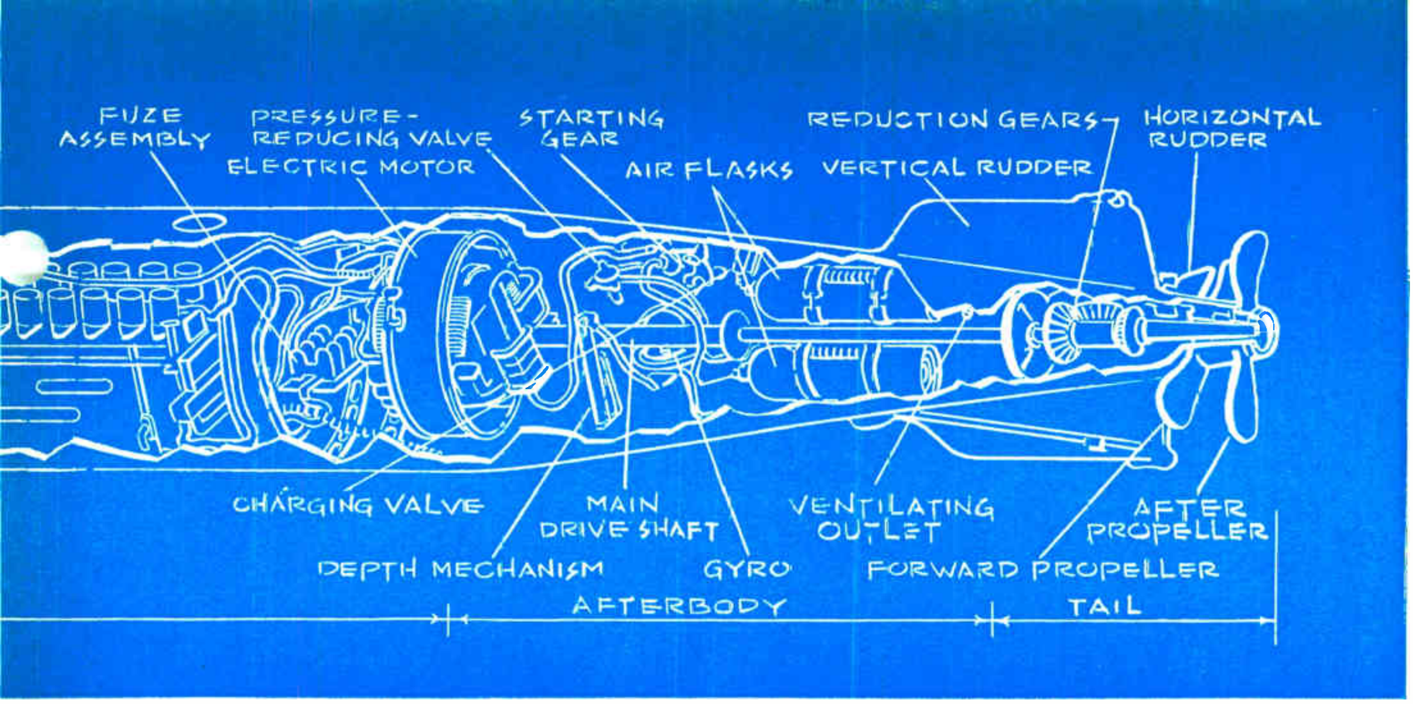
What David Glasgow Farragut meant in his historically famous order, issued aboard his sail-and-steam-driven wooden flagship *U.S.S. Hartford*, would be incorrect by modern naval terminology. He really meant, "damn the floating contact mines," because during the Civil War, the "torpedo" was a mine, a defensive weapon.

A more sophisticated early version used for offensive purposes, however, was the *spar torpedo*. This device consisted of a black powder explosive charge fastened to the end of a long pole, or spar, which was triggered by pulling a lanyard to fire a fulminate percussion cap, which, in turn, detonated the main charge.

Cushing and the 'Albemarle'

Probably the most successful use of the spar torpedo during the Civil War occurred in a naval action on the Roanoke River, near Plymouth, N.C., on the night of 27 October 1864. The powerful Confederate ironclad ram *Albemarle* was used, with deadly effectiveness, in the South's combined operation (a land and sea offensive) to recapture Plymouth and the nearby Union forts. The big ironclad, similar in design to the famous *Merrimac*, sank and damaged several Union vessels in a violent series of encounters. The U.S. Navy was determined to put the ram out of action.

Lieutenant William B. Cushing, USN, with six officers and eight enlisted men, volunteered for the assignment. Under cover of the night and a heavy mist, Cushing stood in the bow of a 30-foot-long (9-meter) steam-powered launch that chugged quietly up the Roanoke River, and



and the U.S. Navy

The war in the air; on the surface of the sea; and beneath the waves soon took on the aspects of deadly accuracy in new weapons systems with the rapid advance of military electronics during the Second World War

Gordon D. Friedlander *Staff Writer*

(Above) Cutaway drawing of the U.S. Navy's electric torpedo, Mark 18, with warhead attached, as viewed from the port side. This basic weapon was used extensively by submarines during World War II.

personally manned the lines controlling the movable spar torpedo. He sighted the *Albemarle* moored alongside a wharf. He immediately ordered full speed ahead, but the launch was detected and challenged by a sentry aboard the ram. This was instantly followed by a volley of rifle shots. Confederate signal fires flared from the shore, illuminating the small Federal launch in sharp relief. To his surprise and chagrin, Cushing saw a log outrigger boom protecting the side of the vessel; the Confederates were prepared for just such an attack.

In desperation, Cushing withdrew the launch about 100 meters; then, driving ahead at flank speed through a withering enemy fusillade, he struck the log barrier with such force that the momentum carried the small launch right over the logs and it came to rest directly under the casemate of *Albemarle*. Cushing pulled the torpedo-firing lanyard at the same instant that the ironclad shattered the night with a cannon broadside at point-blank range. The launch was swamped by the torpedo explosion and riddled with canister shot. Only Cushing and one seaman managed to escape drowning or capture. As the commanding officer of *Albemarle* ruefully put it after his ship settled to the bottom: "They blew a hole in her side big enough to drive a wagon through!" Thus a tiny launch with a determined crew sank a powerful warship to portend the future role of torpedo boats and destroyers in the great naval battles of the 20th century.

Development of the modern torpedo

Credit for the development of the modern self-propelled torpedo is generally given to Robert Whitehead, a British engineer who built the first successful model of his device in 1866. One version of the Whitehead torpedo measured approximately 5 meters long by 36 cm in diameter, and weighed about 136 kg, including an 8-kg charge of black powder for its warhead. The weapon was

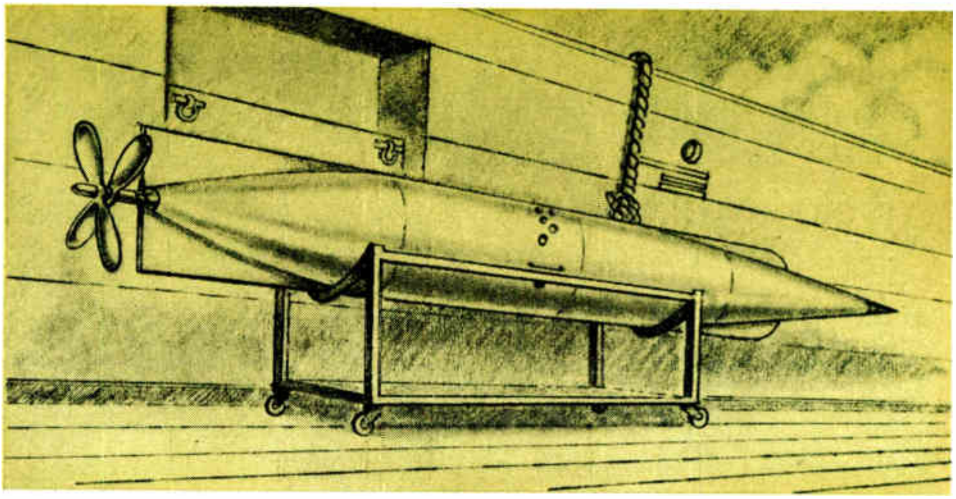


FIGURE 1. Artist's rendering of the original Whitehead torpedo. This low-speed, self-propelled missile of 1866 was driven by a compressed-air engine over short distances.

powered by a compressed-air engine driving a single propeller (Fig. 1). Its running depth beneath the surface was controlled by a hydrostatic valve that operated fins on the horizontal tail surfaces, but there was no rudder for lateral steering control. This weapon had a speed of about 6 knots (2 m/s) and a range of 500 meters.

Subsequent modifications of the original Whitehead design were made in the United States, Great Britain, and Germany. A U.S. firm, the E. W. Bliss Company, successfully employed a steam turbine drive in its version of the Whitehead missile. This weapon, called the Bliss-Leavitt torpedo, was used extensively by the U.S. Navy before World War II. The 50 flush-deck World War I-model U.S. destroyers transferred to the Royal Navy in 1940 were equipped with Bliss-Leavitts.

Propulsion: steam or electric. Torpedoes are propelled either by steam or by electricity. The modern version of the weapon is subdivided into four principal sections (see title illustration, p. 46): the warhead; battery compartment (for electric torpedoes), or air-flask section (for steam-driven torpedoes); the afterbody; and the tail.

In homing torpedoes—to be discussed later under this subject heading—the homing mechanism is housed in a detachable nose section forward of the explosive-filled portion of the warhead. Torpedo exploders operate either on contact with a target, or on passage within a preset distance from the target. Since a ship is not usually armored on the bottom of its hull, a magnetic exploder that detonates the warhead directly beneath a ship's keel is theoretically effective. Figure 2 shows a typical midship section of a World War II battleship and some of the armor protection designed to give these warships maximum protection against torpedo attack by missiles with contact or magnetic exploders. Note the unique torpedo blister used for many years on Royal Navy battleships. With this type of structural installation, the water between the blister and the hull acted as a cushion to minimize hull damage from the force of contact torpedo and mine explosions. A number of U.S. battleships and the aircraft carrier *Saratoga*, all modernized before World War II, were fitted with blisters. The Royal Navy, however, used them more extensively, even though the drag of such massive structures reduced the maximum speed of its warships.

The Mark 18 torpedo (a basic weapon system), is a single-speed missile that is driven by an electric motor and is designed to be launched from a submarine. It is about 20 feet long (6 meters) by 21 inches (53 cm) in diameter. It can travel about 4000 meters at a speed of 29 knots (15 m/s). This missile carries a 300-kg charge of Torpex, an explosive ideally suited for underwater detonation. The advantages of the Mark 18 electrically driven torpedo are

1. The absence of the wake caused by the exhaust gases in the steam-driven type.
2. No change in weight during the firing run (steam torpedoes lose weight as their fuel is expended); hence, better accuracy and depth control are usually achieved.

The Navy's Mark 15 torpedo is a steam-driven version that is especially designed for above-water launching from surface vessels such as destroyers, frigates, or PT-boats. This device is 7.3 meters long by 53.3 cm in diameter and weighs about 1600 kg. The Mark 15 is a three-speed weapon capable of traveling 14 000 meters at a speed of 14.4 m/s, 9100 meters at 17.5 m/s, and 5500 meters at 23.6 m/s. The explosive charge weighs about 300 kg.

The air-flask section is the main body of the steam torpedo and it contains compressed-air tanks, water, and fuel. The "torpedo juice" of World War II fame usually consisted of alcohol and Navol (a hydrogen peroxide mixture). The afterbody is the "engine room" of the steam torpedo. It houses the gyroscope, the depth-regulating mechanism, the combustion flask, and the turbine. In operation, the combustion flask converts the fuel-air-water mixture to steam, which drives the turbine at high speed. The turbine is connected to the coaxial, contrarotating propellers by means of reduction gears.

In electric torpedoes, the battery compartment replaces the air-flask section. The batteries provide power for the electric motors, which, in turn, drive the coaxial propellers. Compressed air for the gyroscope is stored in small air flasks in the afterbody. To minimize noise, and early detection by enemy sonar, homing torpedoes are electrically powered throughout, thereby eliminating the air flasks for the gyroscope. In such installations, the gyro is brought up to speed by an electric motor, and both vertical steering rudders and horizontal depth-con-

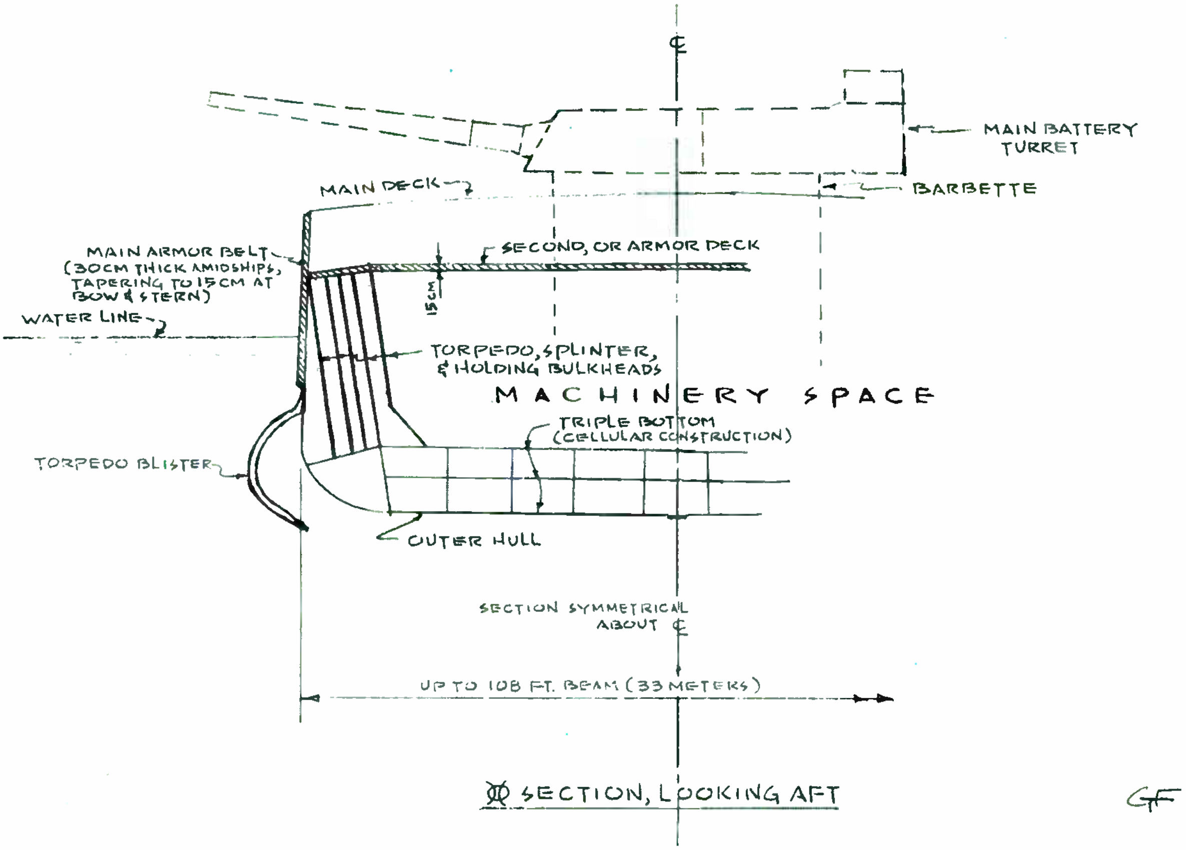


FIGURE 2. Composite midship section of a typical Allied battleship of the World War II period. For simplicity, longitudinal strength members and transverse structural hull framing are not shown.

trol fins are electrically operated. And, as a further noise-reduction technique, homing torpedoes are generally fitted with a single propeller.

Gyroscopic control. The gyroscope acts to establish the initial preset course of the torpedo toward its target by applying corrective movement to the vertical or steering rudders. Further modifications in gyroscope design permitted the introduction of a set angle (up to 90 degrees) into the torpedo's course before the steering rudders assume full directional control. This important advance greatly broadened the field of torpedo tactics by allowing a ship to launch torpedoes at any bearing within a wide angle of heading. In acoustical and homing torpedoes, of course, the electronic controls override the gyro setting at a predetermined proximity to the target.

Torpedo design criteria

Essentially, the problem of torpedo propulsion in World War II was the same as that of submarines: the development of an adequate self-contained power supply within a vehicle of small size to provide high speed and directional accuracy, and to drive internal mechanisms for homing, depth control, and steering.

The ideal torpedo should have high speed and long effective range coupled with silent running. Unfortunately, however, no torpedo has all of these characteristics. Steam torpedoes achieve high speeds (about 21 m/s) over a range of 9100 meters by using the Navol fuel, but these speed and distance attributes are offset by the noise of the turbine and the contrarotating propellers, and the telltale surface wake. Although electric torpedoes are relatively silent, the batteries limit either their speed or their range. Nevertheless, new developments in marine engineering, such as the supercavitating propeller, and in electrical engineering may eventually evolve an ideal underwater missile.

Launching techniques. Most modern submarines launch their torpedoes from tubes that are built as an integral part of the vessel's structure. Many surface warships launch these missiles from deck tubes by firing a black powder charge. Chemical compounds to suppress flame and smoke are frequently added to these charges, and above-water tubes are often equipped with flash-hiders to avoid detection during night actions.

Most submerged tubes, and some above-water launchers, discharge their torpedoes by compressed air. In World War II, all submarines were equipped with devices to eliminate the telltale air bubble caused by firing. In another improved launching technique, the submerged tubes are flooded after the torpedo is loaded; and, upon firing, the "tin fish" is expelled from its tube. This method reduces noise and other firing indications to a minimum. After launching, torpedoes must run for a short distance (this is governed by a preset number of propeller turns) before they become "armed," or

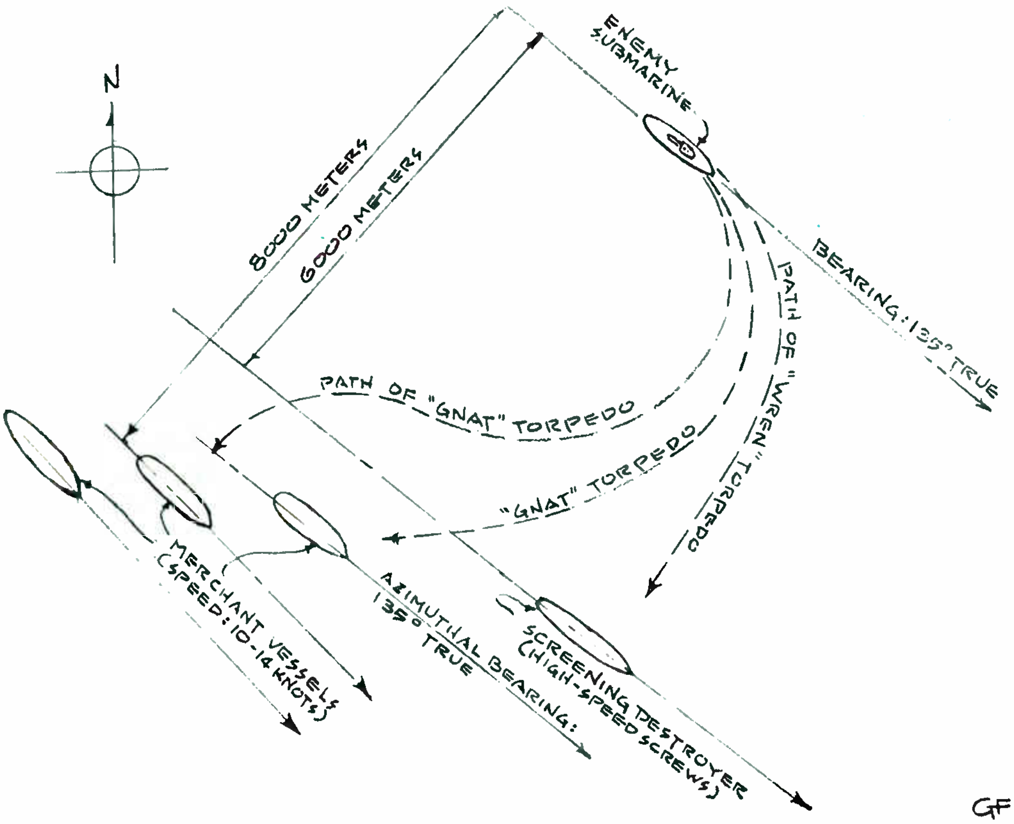


FIGURE 3. Plot of the normal path of the German Gnat and Wren homing torpedoes. Note that the submarine can fire the missiles from its bow tubes while running on a parallel course to the convoy and its high-speed destroyer escort.

ready to explode. This precaution affords a margin of safety for the launching vessel—particularly in using homing torpedoes.

As a further safeguard, in wartime naval operations, the torpedo is usually preprogrammed to explode after a preset maximum number of propeller turns if the vehicle misses its target. This is done to protect friendly ships from blundering into an armed floating "mine," and to prevent the spent missile from falling intact into enemy hands.

Aerial torpedoes

Torpedoes launched from naval aircraft during World War II were practically identical to submarine and surface-ship types, except in size. A typical aerial torpedo, such as the U.S. Navy's Mark 13, was 4 meters long by 57 cm in diameter. It was designed to be launched from torpedo bombing planes flying at low altitudes (50–200 meters) at moderate to high air speeds (60–150 m/s). Aircraft-launched homing torpedoes were usually equipped with small parachutes to reduce the shock of impact with the sea and thereby protect the sensitive electronic guidance mechanism.

Electronic guidance control—acoustical and homing torpedoes

In June 1940, the Office of Scientific Research and Development (OSRD) recommended the investigation of several military projects in the guided missile field, but little practical work was done in this area for the next three years. In 1942, Rear Admiral Julius A. Furer, USN, the Naval Coordinator of NDRC, anticipated that guided missiles such as glide bombs and acoustically steered torpedoes would soon be used by the Germans. The homing torpedo, for example, could be designed to home on sounds such as ship propeller noises generated by the target vessel, on echoes reflected from the target by a sonic transmitter within the missile, on electromagnetic disturbances set up by a moving vessel, or on a combination of any of these principles.

First, the warning—then, the blow. In February 1943, a survivor of a sunken German U-boat remarked, during a routine prisoner interrogation, that a new type of German torpedo was being tested in the Baltic Sea. And in June of that year, another prisoner—a German navy technical rating—gave the Coordinator's office many details on the construction and operation of the new weapon. From this man's detailed description, it was apparent that the control mechanism was based on acoustic and not on echo principles.

By way of parenthetical explanation at this point, "active acoustic" torpedoes generate sound signals, by means of built-in transducers, similar to sonar and home on the echo received from the target. "Passive-acoustic" torpedoes home on noise generated by the target. Thus the new German weapon was judged to be of the latter type.

An Allied study of more than 350 ship-sinking reports

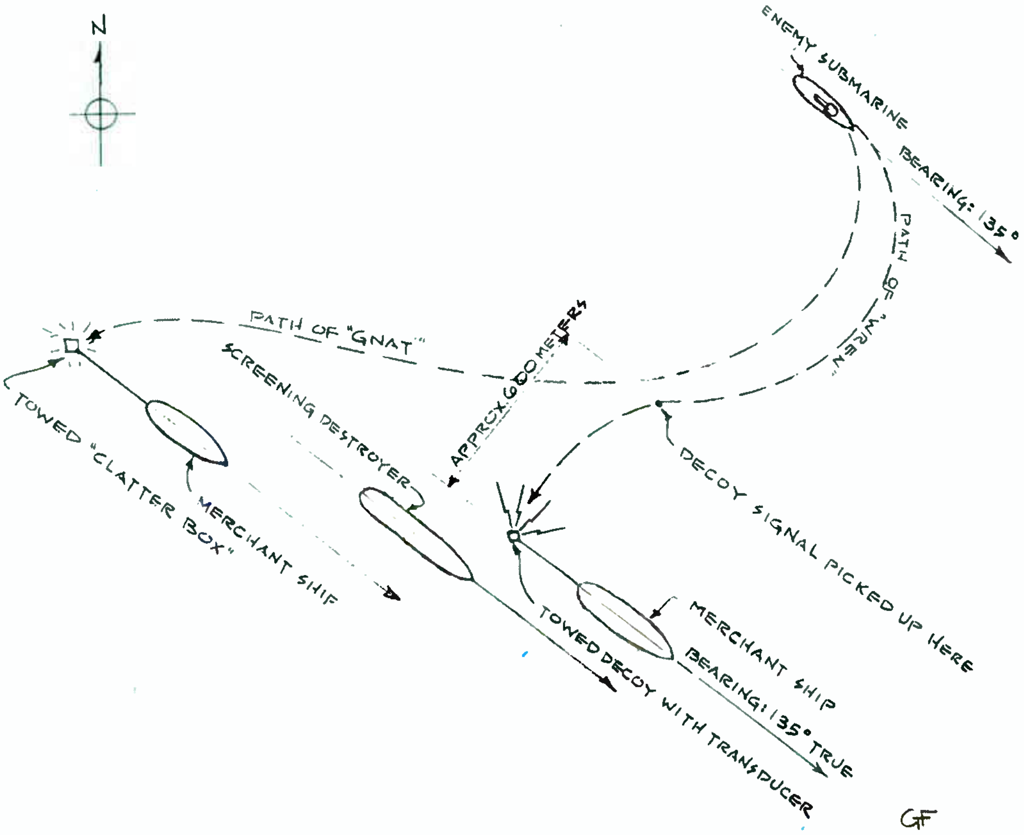


FIGURE 4. Chart showing approximate paths of the Gnat and Wren missiles when "decoyed" by towed "clatter boxes" and false-signal transmitters.

revealed several widely scattered observations of erratic and unconventional torpedo behavior. For instance, the experience reported by survivors of the American freighter *Robert E. Lee*, sunk by a U-boat in the Gulf of Mexico, was considered very unusual. These witnesses stated that the torpedo was sighted running parallel to the course of their vessel at some distance abeam. Then, suddenly, the missile turned 90 degrees on an intercept course with the freighter. The detonation occurred on impact with the target seconds later.

On 25 August 1943, German planes, maneuvering out of range of Allied surface-vessel antiaircraft fire in the Bay of Biscay, released radio-controlled glide bombs in an air-to-surface attack. In the following weeks, German aircraft, each equipped with a radio-controlled glide missile and an electronically guided high-angle bomb, sank many Allied merchant ships in both the Bay of Biscay and the Mediterranean. These new weapons inflicted heavy damage on the Royal Navy battleship *H.M.S. Warspite* and the U.S. Navy cruiser *Savannah*.

Gnats and Wrens. The Germans dubbed their homing torpedo, for use against merchant shipping, the "Gnat." A more sophisticated version of this weapon was the "Wren," designed to home on the acoustical frequency of the high-speed propellers of destroyers and destroyer escort vessels (Fig. 3).

These German weapons were initially aimed toward the general vicinity of a target vessel. When they approached sufficiently close for the acoustic detection system to get a fix on the target (usually at a distance of a few hundred meters), the torpedo was steered the remaining distance by servomechanisms. Detonation was accomplished either by contact or by means of an influence exploder.

Fortunately for the Allies, the Germans were not geared for the mass production of these weapons. Nevertheless, they were frightening and effective devices, and immediate countermeasures had to be taken.

The staff scientist on acoustics in the Naval Coordinator's office began work on these countermeasures in conjunction with the Underwater Sound Laboratory of the NRL. One of the devices developed for neutralizing the Gnat was a "clatter box"—a mechanical noisemaker in which an air hammer was used to beat upon a steel plate. When towed astern of a merchant vessel, the device would "decoy" the homing torpedo away from its target. Thus the Gnat would either expend its propulsive power or explode harmlessly near the decoy. To decoy the Wren, a merchant ship or slower warship would tow a decoy containing a built-in transducer that would simulate the noises of a destroyer's high-speed screws (see Fig. 4).

Acoustic and magnetic mines

Experimentation with acoustic and magnetic mines was actually carried out by both the Allies and Germany before the end of World War I. But it was the Germans who first used these devices, dropped by aircraft, to mine the harbors of the French channel ports shortly after the outbreak of World War II in 1939. These stationary weapons were also laid by submarines and surface craft. The earlier versions of the mines were of the passive-acoustic type and were detonated by noise emitted from the target ship as it passed nearby. Since a mine lay on the bottom of shallow channels and roadsteads, it could contain a heavy explosive charge (250–700 kg) of Torpex or TNT.

Often the acoustic triggering mechanism was used in conjunction with a magnetic sensor. This combination made defensive minesweeping operations difficult since the mine would not explode unless both an acoustic and a magnetic signal were received simultaneously. The minesweepers, however, were eventually equipped with high-power underwater acoustical generators to detonate these mines at a safe distance.

The acoustic and magnetic mines, in themselves, contain the elements for their own neutralization with time. Drifting mud, silt, and increasing marine growths will foul the mines. Also, the continuous battery drain will eventually render the weapon ineffective.

Another minesweeping technique was essentially similar to the method employed for decoying homing torpedoes. Although the British minesweepers used both built-in and towed "hammer boxes," the U.S. Navy vessels employed on such missions invariably favored the towed versions.

Degaussing: a defensive measure

Essentially, "degaussing" is a technique whereby the magnetization of a ship is neutralized by properly located and oriented current-carrying coils that produce a magnetic field of desired strength and direction.

A steel ship contains structural components of many different ferromagnetic characteristics. Some parts become magnetized during construction and remain so for a considerable period of time thereafter. Other parts of the vessel are "soft" iron, which does not retain a permanently magnetized condition, but instead becomes magnetized by induction in the earth's magnetic field. Thus a ship has a two-part magnetization: the semipermanent component, and the temporary or induced component. This magnetization causes deviation of the magnetic compass aboard the vessel—and it can trigger magnetic mines.

One method of neutralizing the magnetic field is to install degaussing coils in which currents are maintained to produce countercomponents that will neutralize the existing magnetization of the ship. Sets of these coils are arranged to compensate separately for three components of the magnetization. Since the largest component of the earth's field is vertical, the main coils have their planes horizontal to produce a compensating vertical field. The two horizontal components are those parallel to and perpendicular to the longitudinal axis of the vessel. These components are compensated by sets of coils with vertical planes. One set, with planes parallel to the length of the ship, compensates for the fore-and-aft component; the set with planes parallel to the length of the ship compensates for the athwartship component.

The current in degaussing coils must be adjustable because of the variation in the ship's magnetization. The induced component, in particular, varies as the ship changes position and direction.

In operation, two predominant subtechniques were employed in ship degaussing:

'Flashing.' This consisted of placing a huge temporary coil longitudinally all around the hull of the ship and then reversing the polarity of the permanent magnetic field. But this process was expensive and each treatment lasted only a few months before it had to be repeated.

'Wiping.' This method required the moving of a single cable, with about a 3000-ampere load, up and down the ship's side, section by section.

Magnetic and influence exploders

The detonation of torpedoes when in proximity of the vulnerable unarmored underside of a warship's hull (Fig. 2) had long been the objective of naval researchers of the major world powers. A proximity exploder of this type would greatly increase the destructive capabilities of the missile and might possibly "break a ship's back" by rupturing the keel girders, side keelsons, and other primary longitudinal strength members. Thus the Royal Navy, the U.S. Navy, and the German *Kriegsmarine* spared no expense on the development of magnetic exploders. But it was a difficult problem, because the torpedo often fired prematurely from excessive rolling, pitching, or yawing in rough seas (see "World War II radar: the yellow-green eye," IEEE SPECTRUM, p. 65, May 1966).

In 1943, the U.S. Navy turned this problem over to the OSRD with the request that an exploder be developed that would be insensitive to the roll, pitch, and yaw that could be expected in open sea operations. To make the design universally applicable to all torpedoes, the U.S. Navy's aircraft torpedo, Mark 13, which was subject to the roughest motion and impact upon drops from airplanes, was selected as the test weapon.

The result of intensive investigation, testing, and R&D efforts, was the Mark 9 Torpedo Exploder. This device was successfully adapted to aircraft-, surface-vessel-, and submarine-launched missiles—both steam- and electric-driven. The Mark 9 employed highly sensitive electrical components and parts especially designed for the rugged VT (variable time) fuze. This exploder was also equipped with an anticountermine switch, which prevented premature firing by protecting the device from the shock waves that could result from the explosion of other torpedoes in a spread firing, or a defensive salvo of enemy countermine charges (Fig. 5).

Production of this exploder was awarded to the International Harvester Company in late 1944, and the device was ready for operational service when the Japanese surrendered in August 1945.

The proximity fuze

The primary objective in antiaircraft gunfire is the explosion of the projectile within an intercept zone in which a maximum number of shell fragments will strike the flying target. Even with predictors and fire-control computers, there was still a very low ratio of "kills" to the number of rounds fired. In 1940, "good" antiaircraft fire from 88- to 120-mm weapons shot down one plane for every 2500 rounds fired. This startling figure was caused by poor range finding rather than by poor gun laying, because the existing fire-control systems at that time furnished good results in calculating the angles of fire. The most efficient artillerymen could not hope for a direct hit by a contact shellburst. Therefore, reliance had to be placed on time-fuzed shells. Assuming perfect fuze functioning, the shell would burst at an instant when the

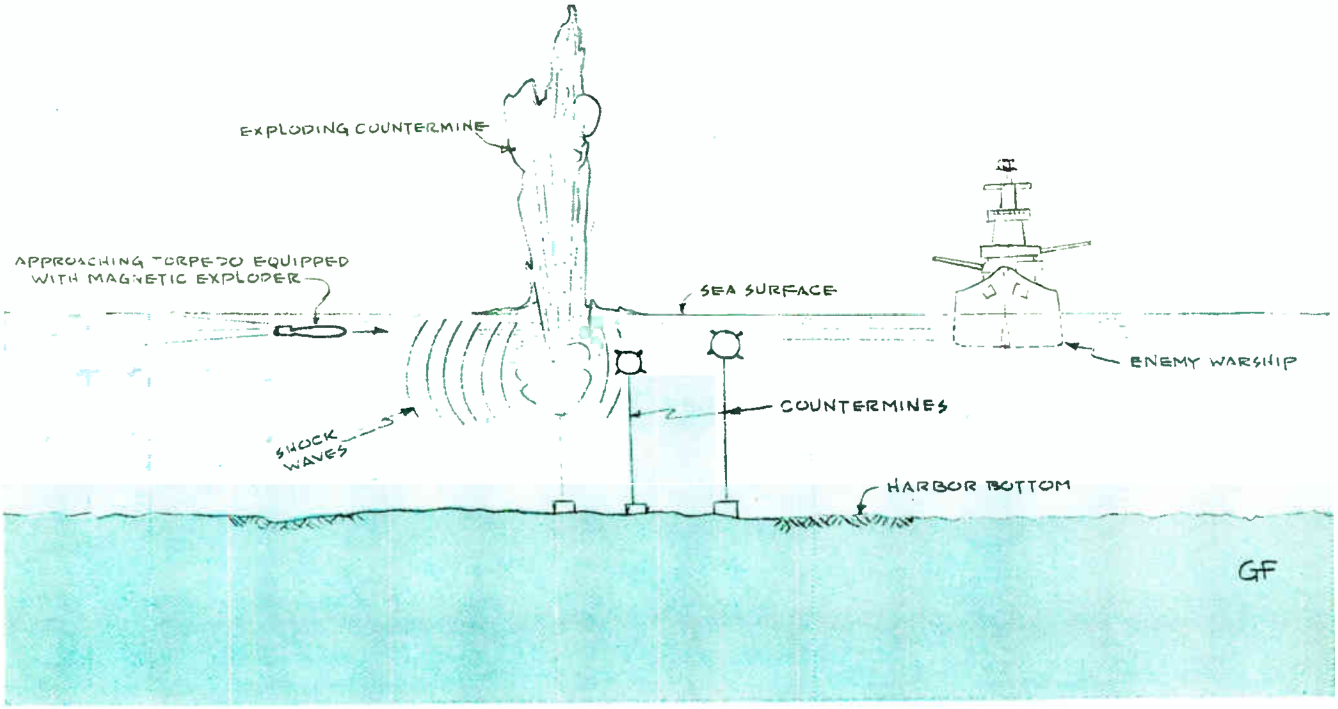


FIGURE 5. A common defensive technique against torpedoes fitted with earlier versions of the magnetic exploder was the detonation of acoustical countermines to produce shock waves, which—hopefully—would cause the premature triggering of the delicate exploder mechanism in the torpedo's nose.

plane was in the intercept zone. But all this was a very big assumption since there was a large margin for errors. Such errors could occur in

1. The manufacture of the fuze itself.
2. The accuracy of manual or automatic time settings.
3. The estimated allowance for "dead time"—the interval between the fuze setting and the instant of firing the gun.

These were a few of the problems confronted by antiaircraft gunners whose weapons were fired from land-based steady platforms. Consider now the additional complications thrown into the general problem in attempting to control these same projectiles when fired from the moving and unsteady gun platform that is represented by a warship at sea. Prior to World War II, the errors in fuze settings and gun laying necessitated "saturation firing," in which it was hoped that a curtain of shellbursts from the land-based antiaircraft barrage would down some of the attacking planes. This was generally not a very effective defense, however, since attacking aircraft could approach from many different directions.

Some early R&D efforts. As early as 1931, the U.S. Navy's Bureau of Ordnance (BuOrd) had toyed with the idea of developing an infrared A.A. fuze that could be triggered by the heat from an enemy aircraft's engine. But like da Vinci's imaginative concepts, it was ahead of the existing technology at that point in time.

By mid-1940, major improvements in military aircraft capabilities and a deteriorating world situation demanded the investigation of every possible avenue for the development of the proximity fuze. At a joint meeting of the NDRC and the Navy Department Council for Research in July of that year, it was agreed that the development of such a fuze was feasible by utilizing either electronic or photoelectric devices. A month later, BuOrd gave influence A.A. fuzes top priority over all NDRC projects. In August 1940, Section T of the NDRC was established and headed by Dr. M. A. Tuve (F, IEEE) of the Carnegie Institution, and in November 1940, the National Bureau of Standards joined Section T on one phase of the fuze project.

The crash program. Early in 1941, all Navy contractors were advised to concentrate their efforts on the development of an electronic fuze by several different approaches; among these were

1. Ground-transmitted radio signals that would be reflected by the target and received by the fuze's detector element to activate the electric detonator.
2. The design of a fuze capable of internal sensing for the ignition of the demolition train.

This latter approach was ultimately accepted as the more logical. When completed, it would contain four major components: a miniature radio transceiver, complete with capacitor and amplifier; a battery; an explosive train; and the necessary safety devices to protect military personnel when handling the armed projectiles (Fig. 6).

Theoretically it was believed that the fuze transmitter, by itself, could not produce enough signal intensity to trip a thyratron switch. But as the shell approached an airplane, the radio waves reflected from the target would

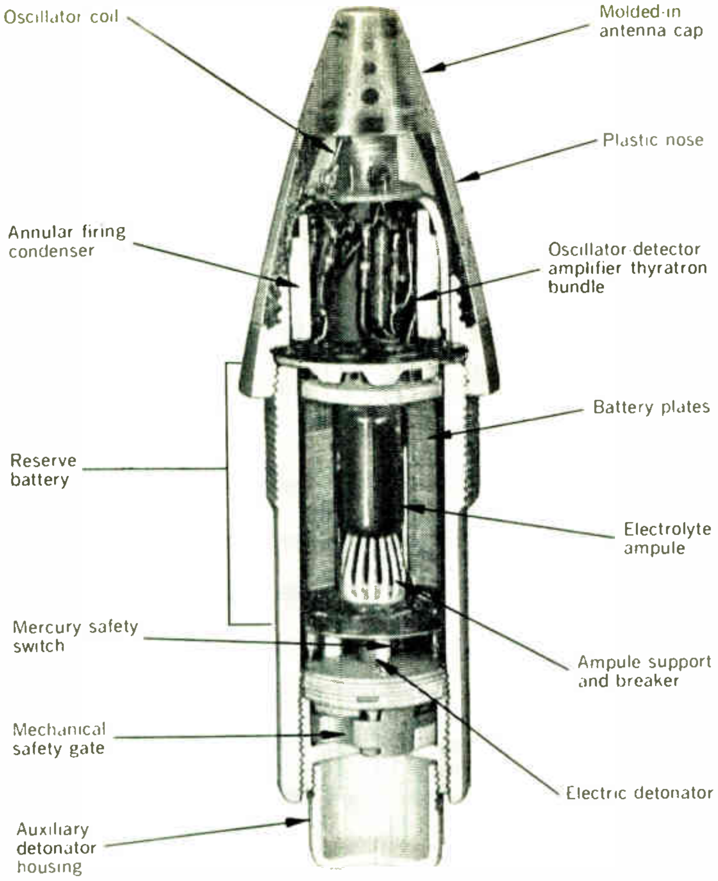


FIGURE 6. Cutaway section of the wet-cell-powered proximity (variable-time) fuze. Mass production of this device —one of the most important technical breakthroughs of World War II—began in 1943.

FIGURE 7. Electronics technician holds a conventional 5-inch cathode-ray oscilloscope tube and a subminiature radio tube of the type used in the proximity fuze.

increase and come into phase with the fuze-generated signal so that, when the projectile came within the maximum fragmentation pattern zone, the combined augmented waves—transmitted and reflected—would be strong enough to trigger the thyratron switch. This event would release the energy in the charged annular firing condenser to ignite the explosive train electrically.

To translate the design from paper to a working prototype model, however, required the development of subminiature electronic components (Fig. 7) sufficiently durable to withstand an accelerative force 20 000 times more than gravity (at the instant the shell leaves the gun barrel) and a centrifugal force produced by approximately 500 r/s (the spin imparted to the projectile by the gun barrel rifling). All of these sensitive—yet rugged—parts had to be contained in a package whose volume was about equivalent to that of a pint-sized milk bottle.

In this phase of the development period, the thyratrons were handcrafted by technicians of the Western Electric, Raytheon, Hytron, Erwood, and Parker-Majestic companies. Quality, of course, varied; but any shortcomings were corrected by frequent redesign and modifications until the standardized handmade devices could be tooled for mass production.

In November 1941, the Crosley Corporation was retained under contract by BuOrd to conduct independent research in fuze construction under the supervision of the NDRC. This electronics firm was expected to provide realistic and practical engineering design for mass production rather than development. Meanwhile, NDRC continued to make contracts on the general project with numerous industrial firms and universities. By this time, however, the rate of development was so swift that it outgrew all available research facilities.

The first test firing. On 29 January 1942, a pilot production group of proximity fuzes, with subminiature electronic components and dry-cell batteries, were affixed to standard 5-inch (127-mm) antiaircraft shells and fired from a 5-inch 38-caliber naval dual-purpose gun. The gun was laid to hurl the projectiles over a 9.25-km trajectory. Fifty-two percent of the shells fired activated themselves by proximity to water. Although this may seem to be little better than one out of two, it represented a far higher ratio than anything possible by saturation firing. On this basis, BuOrd authorized the Crosley people to begin limited production of the fuzes without delay.

Bugs in the battery. Initially, it was believed that a small dry-cell battery would be adequate as an energy source; but during the R&D period it was discovered that a large percentage of these cells could not withstand the shock of gunfire, and also had a short life duration under shipboard storage conditions. Therefore, parallel research was undertaken to develop improved dry cells and a wet battery in which the electrolyte would be separated from the electrode until after the shell was fired. The wet-cell approach proved more feasible, and this evolved into a cylindrical battery (Fig. 6), in which the electrolyte is carried in a glass ampule at the center of a cylindrical shell of battery plates. When the A.A. gun is fired, the shock smashes the ampule to release the electrolyte. The centrifugal force created by the spin of the shell forces the liquid between the plates to activate the battery. The new battery was ready for testing in February 1942.

The second 'dry run' and the service test. A second test, similar to that of 29 January, was conducted in April 1942. On this occasion, 70 percent of the fuzes detonated. Other simulated experiments included firing at a dummy plane suspended from a barrage balloon. In all cases, the new battery produced gratifying results.

The first precombat service test of the now-designated VT (variable-time) fuze was conducted on 12 August 1942, during the shakedown trials of the new cruiser *U.S.S. Cleveland* on Chesapeake Bay. Radio-controlled drone planes were used as targets. Although the drone planes were put through every possible evasive maneuver, all three aircraft were destroyed by the bursts of four proximity-fuzed shells. This result was particularly astounding because only 10 percent of *Cleveland*'s gun crew were experienced personnel; the other 90 percent were newly enlisted ratings serving aboard their first ship.

The 'baptism of fire.' In mid-November 1942, some 5000 proximity-fuzed shells in storage at the Mare Island (Calif.) Navy Yard were transported to Noumea for distribution to warships of a naval task force in the South Pacific. The Japanese got their first sample of the new weapon when one of their four bombers attacking the task force was shot down by the second salvo of proximity-fuzed ammunition from the cruiser *U.S.S. Helena*. This action occurred on 5 January 1943.

Since the proximity fuze represented an investment of millions of dollars in R & D and production efforts, it was absolutely essential to prevent a dud shell from falling into enemy hands. Thus, for the next 1½ years, the use of the VT fuze was restricted to naval warfare and it could not be employed in the naval bombardment of enemy-held land fortifications where low air bursts would have been very effective.

During 1943, about 9100 rounds of proximity-fuzed and 27 200 rounds of conventional time-fuzed 5-inch A.A. shells were fired by the U.S. Navy. Fifty one percent of the hits on enemy aircraft were scored by the VT-fuzed ammunition.

Usage of the VT fuze during 1944

In June 1944, the Allies were faced by a new threat from the continent when the German V-1 "buzz bombs" began to fall in ever-increasing numbers on London. These unmanned, jet-propelled weapons could not be effectively neutralized by the Royal Air Force and conventional antiaircraft shells. The Combined Chiefs of Staff agreed that the proximity-fuzed A.A. shells would have to be used in the defense of London. Hundreds of A.A. gun batteries were removed to the Channel coast where they could fire at the incoming buzz bombs over water. This interception served two practical and humane purposes:

1. The downed buzz bombs would explode in the Channel and not over the English countryside or towns.
2. There would be no chance of a dud shell being recovered by enemy agents.

The percentage of hits scored by the VT-fuzed shells was very impressive. In the final month of the 80-day-long flying bomb attacks, 79 percent of the German V-1's were intercepted and shot down by proximity-fuzed A.A. shells. (During the first weeks of the attacks, only 24

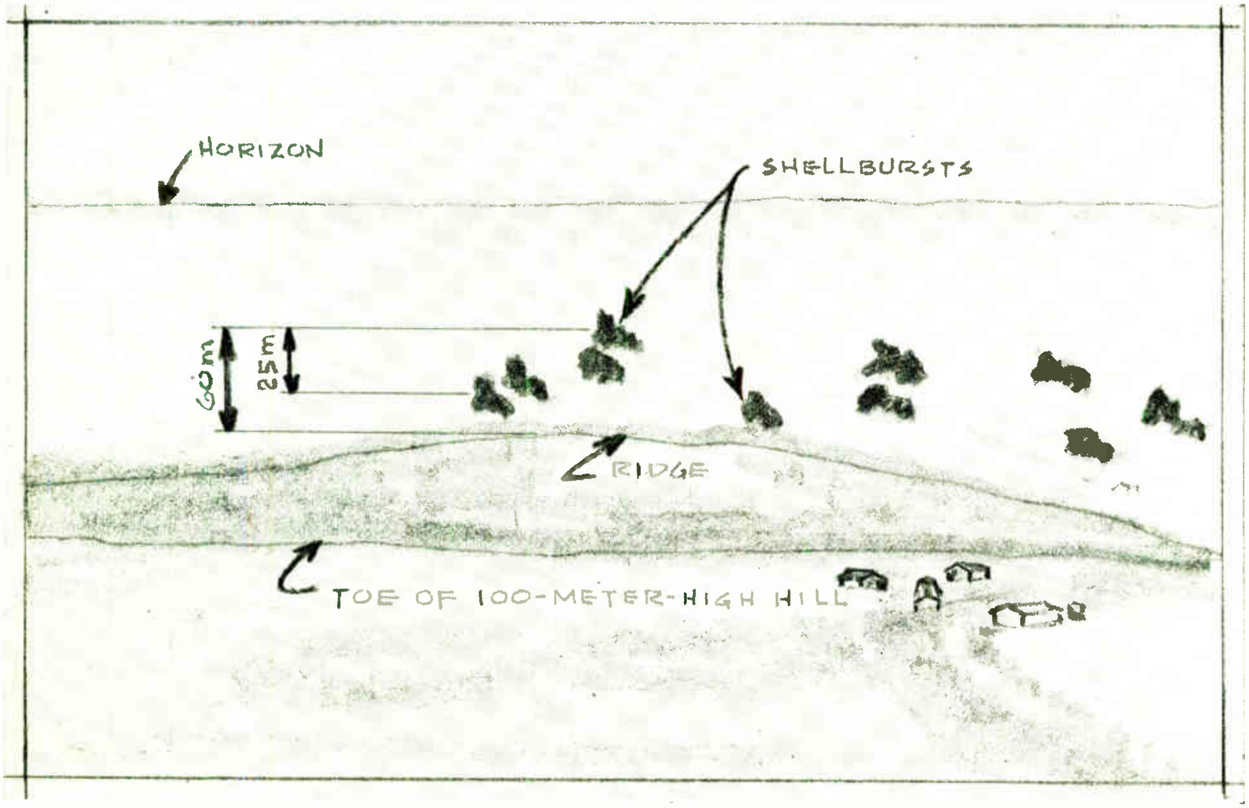


FIGURE 8. Drawing (made from a U.S. Army photograph) showing low air bursts of 105-mm proximity-fuzed shells over an enemy-held hill.

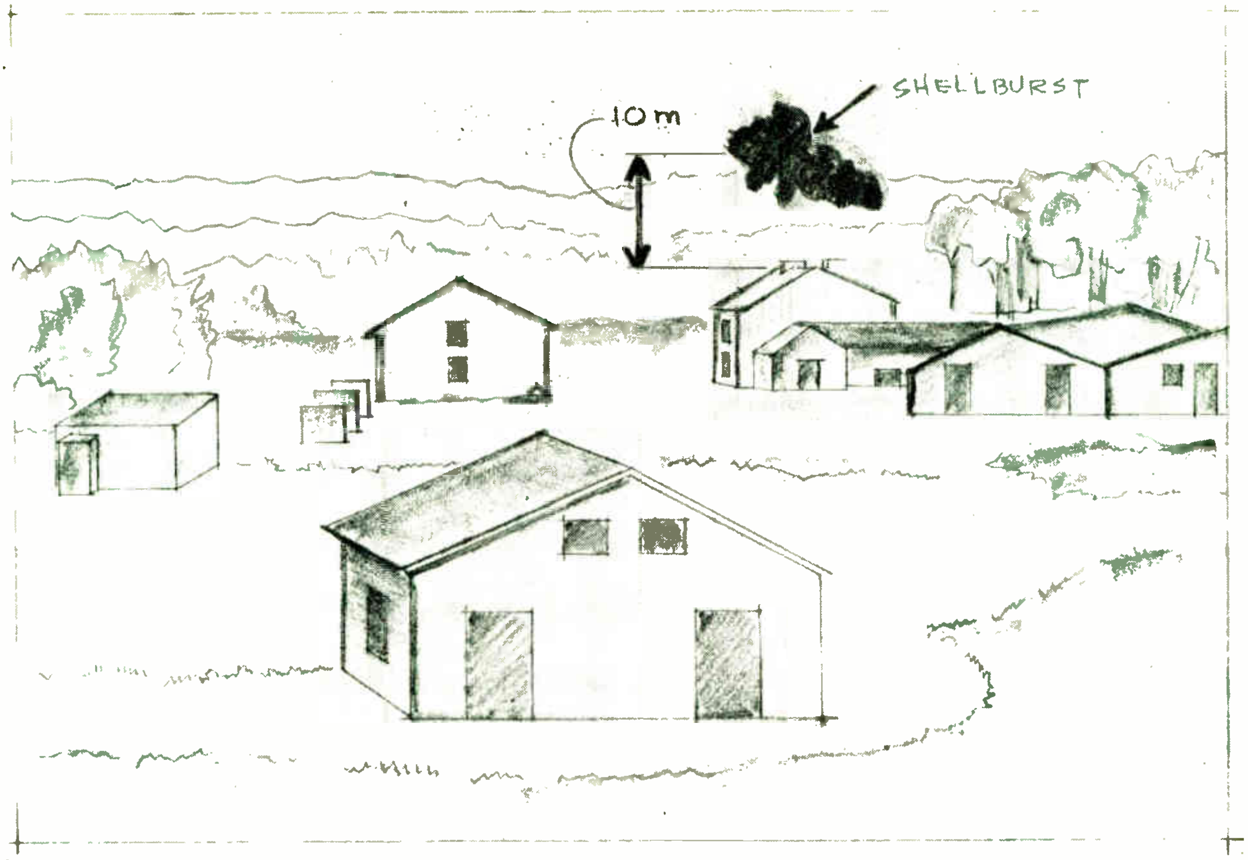


FIGURE 9. Sketch showing a very low air burst of a proximity-fuzed 155-mm howitzer shell directly over enemy-occupied buildings on level terrain.

percent of these weapons were destroyed by the R.A.F. and conventional A.A. fire.) On the final day of the large-scale attacks, only four of 104 flying bombs penetrated the Allied defenses to reach their targets.

In September 1944, dire necessity forced the Allies to use the proximity fuze in land-based A.A. operations when the Germans turned their buzz bombs on the port of Antwerp. And, in December 1944, when Field Marshal von Rundstedt launched his famous counterattack in the Ardennes (Battle of the Bulge), the proximity fuze was adapted to a new application—that of antipersonnel artillery fire against enemy infantry. The fuze was affixed to the shrapnel shells of 105- and 155-mm howitzers and self-propelled rifles for low-level air bursts over hills (Fig. 8) and flat terrain (Fig. 9) for maximum effectiveness against troop concentrations. The deadly showers of high-velocity shell fragments panicked the startled Germans whose hastily dug foxholes provided no shelter from the "funny fuze."

'ASW'—postwar style

By comparison with today's sophisticated antisubmarine warfare (ASW) systems, many of the military electronics devices of World War II are almost as obsolete as the bow and arrow. Nevertheless, these systems of almost a generation ago were the basis for such contemporary weapons as the antisubmarine rocket (ASROC) and the formidable array of surface-to-air missiles now used by the U.S. Navy and NATO forces. But the remarkable military missiles of the present are the result of the pioneering efforts made by the dedicated civilian and naval scientists, engineers, and technicians who "produced the impossible" in naval weaponry in a grim race against time during the darkest days of the Second World War.

Epilogue

You serve a 5-inch gun on a convoy run
And hear the glide bomb's scream.
You expect the shout of the bow lookout:
"Torpedo wake—starboard beam!"
—*from* "*Winter, North Atlantic*"

The author wishes to thank Captain L. S. Howeth, USN (Ret.) for his cooperation and assistance in providing some of the illustrations for this two-part series. His fine text, listed in the bibliography, provided an excellent background to the history of the development of the proximity fuze. Finally, the author wishes to thank himself for remembering enough of his World War II naval construction experience—and tactics—to delineate the four sketches (Figs. 2–5) 24 years later. All halftones are reproduced from official U.S. Navy, Army Signal Corps, and Army Air Force photographs.

BIBLIOGRAPHY

Baxter, J. P., 3rd, *Scientists Against Time.* Boston: Little, Brown, 1946.

Furer, J. A., "Naval research and development in World War II," *J. Am. Soc. Naval Eng.*, vol. 62, pp. 99–137, Feb. 1950.

Howeth, L. S., *History of Communications—Electronics in the United States Navy.* Washington: United States Government Printing Office, 1963.

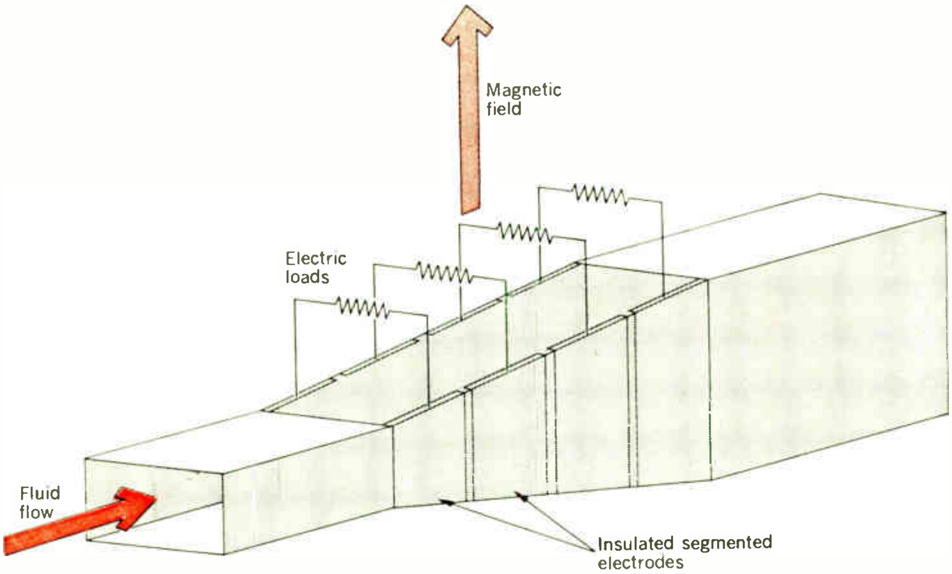


FIGURE 1. Schematic diagram of an MHD converter.

Electrogasdynamic energy conversion

Because EGD conversion has several outstanding potential advantages over other methods of large-scale direct energy conversion, considerable research and development work is now being done on systems employing the EGD principle

Edward M. Walsh *Virginia Polytechnic Institute*

Like the earlier magnetohydrodynamic (MHD) concept, EGD conversion is being seriously considered by the utilities as a possible future means for obtaining large-scale production of electric power. Probably the principal advantage of the EGD converter is that a high gas temperature is not a basic requirement. In addition, the EGD system is potentially capable of generating ac power directly at transmission-line voltages with the use of conventional or nuclear energy sources. Following a brief discussion of MHD conversion, this article reviews the basic theory of EGD conversion and describes a converter system now under development.

The electrogasdynamic (EGD) converter is the latest entry in the race to convert heat directly into electricity on a large scale. Its arrival has been more spectacular than that of the other contestants. Within a short time following the development of the fossil-fueled EGD process, the Office of Coal Research, Department of the Interior, contracted with Gourdine Systems, Inc., and Foster Wheeler Corporation to construct and operate a coal-fired pilot plant. The plant has since been built at Foster Wheeler's Carteret (N.J.) laboratory and is now serving to test the large-scale feasibility of the EGD concept. In addition, the EGD concept is being extensively investigated by research teams at Wright-

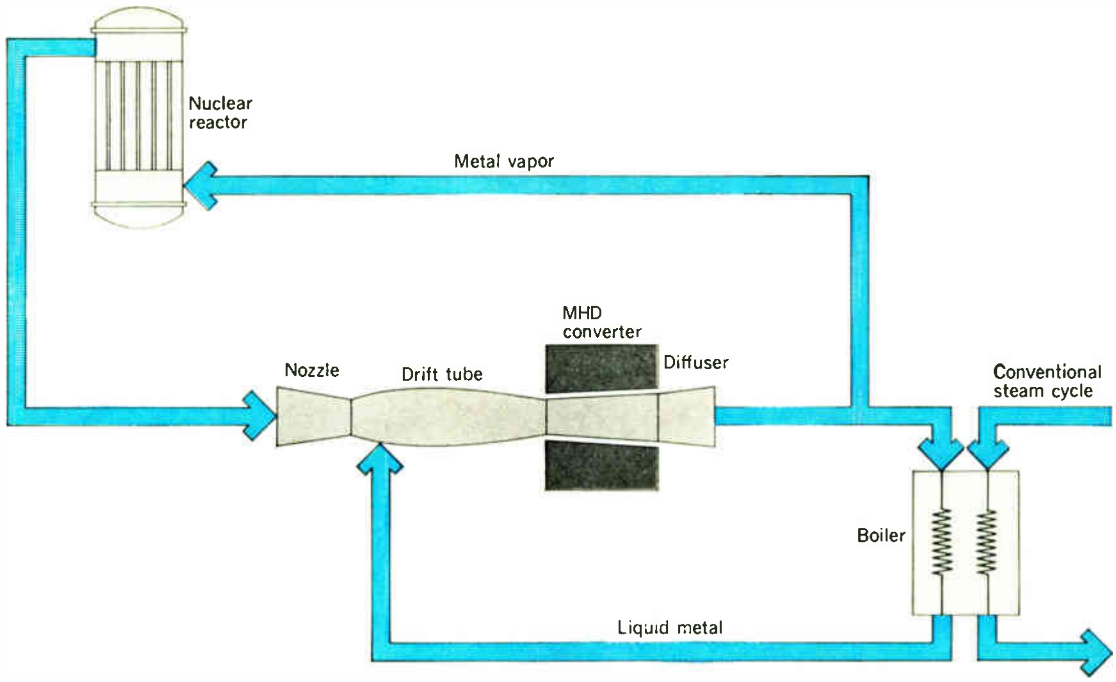


FIGURE 2. Schematic diagram of two-phase MHD cycle.

Patterson Air Force Base and at Curtiss-Wright in New Jersey.

MHD conversion

Prior to the introduction of EGD only the magnetohydrodynamic (MHD) concept attracted the interest of the electric utilities as a possible means of large-scale power production.[1] Generation of electricity in the MHD converter depends on the fact that a voltage is produced when a conductor is caused to move through a magnetic field. The conductor in the MHD converter is a fluid, either a hot ionized gas or a liquid metal, which is forced through a duct as depicted in Fig. 1. The electric load is placed across the insulated electrodes, which are usually segmented to reduce losses caused by the Hall effect.

Despite the many advances made over the past few years in the development of the MHD converter there are still significant difficulties that must be overcome before there is any likelihood that MHD will be adopted by the power utilities. For example, in most experimental converters a gas is used as the working fluid. Since gases at moderate temperatures (1000°K) have unacceptably low conductivities, it has been necessary to use extremely hot gases in which the conductivity is increased by thermal ionization. However, even at temperatures as high as 2500°K, satisfactory conductivities are not achieved without the addition of a small percentage (one percent) of seed material, such as cesium or potassium carbonate. These additives ionize readily and provide the necessary charge carriers to increase the gas conductivity. In practice this solution is not altogether satisfactory, since economics dictate that the seed material be recovered. The possibility of improving the gas conductivity by nonequilibrium ionization methods is under study.[2,3] However, even though the technical feasibility of such methods is largely accepted, there is little experimental evidence to justify nonequilibrium ionization at high specific power and moderate gas temperatures (less than 1800°K).[4]

Although it is possible to achieve high gas temperatures by the combustion of fossil fuels in air, the corrosion and insulation problems associated with such a process are significant. The possibility of using a clean, inert, seeded gas by associating the MHD closed-cycle generator with the nuclear reactor has been considered.[5] However, although the exit temperature from the OECD Dragon high-temperature helium-cooled reactor has been found to be as great as 1133°K it is still far from the minimum 1800°K temperature requirements of the gas MHD converter.

Liquid-metal MHD converters. The fluid conductivity problems, and consequently the minimum temperature requirements, of the gas converter have been eliminated by the use of a liquid metal as the working fluid.[6] Such a converter can also generate three-phase alternating current by utilization of the linear induction generator principle.[7] Many of the proposed liquid-metal systems operate with a two-phase fluid.[6] For example, Fig. 2 shows the two-phase cycle proposed by Prem of Atomics International. The heat source vaporizes some of the liquid metal, which expands through a supersonic nozzle where its thermal energy is converted into kinetic energy. Atomized liquid metal from the second fluid loop is injected downstream of the nozzle. As the two-phase fluid moves through the drift tube the high-velocity vapor phase condenses about the liquid droplets and so, due to momentum exchange, the fluid that leaves the drift tube and enters the MHD converter is essentially a high-velocity liquid.

Although the development of the liquid-metal converter has eliminated some of the important problems of

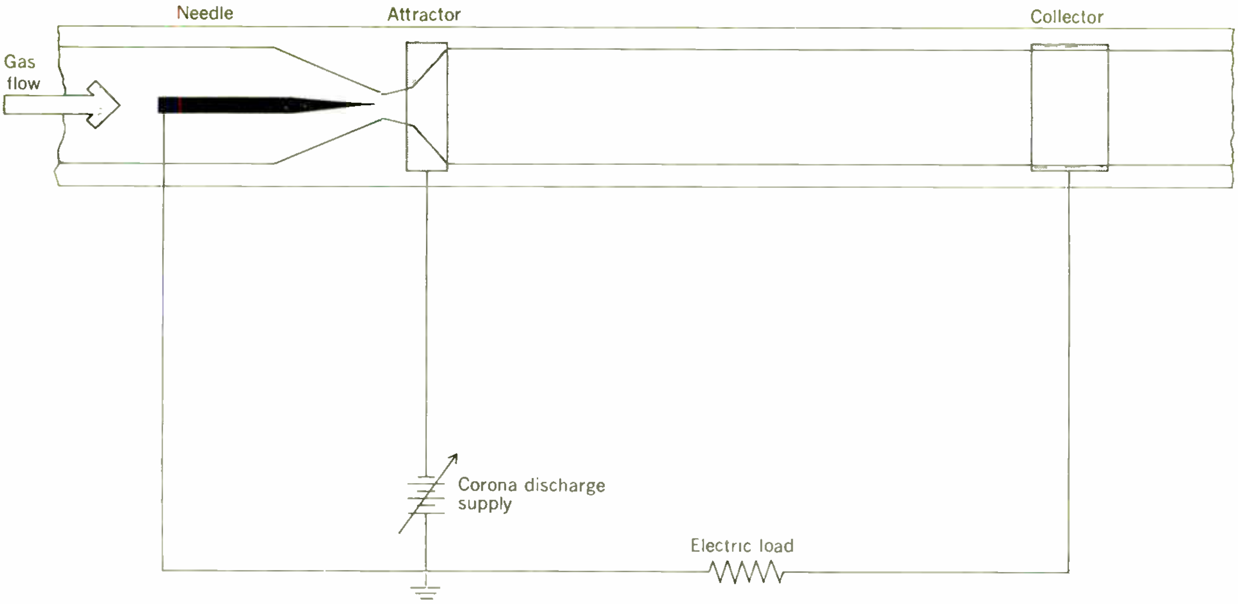
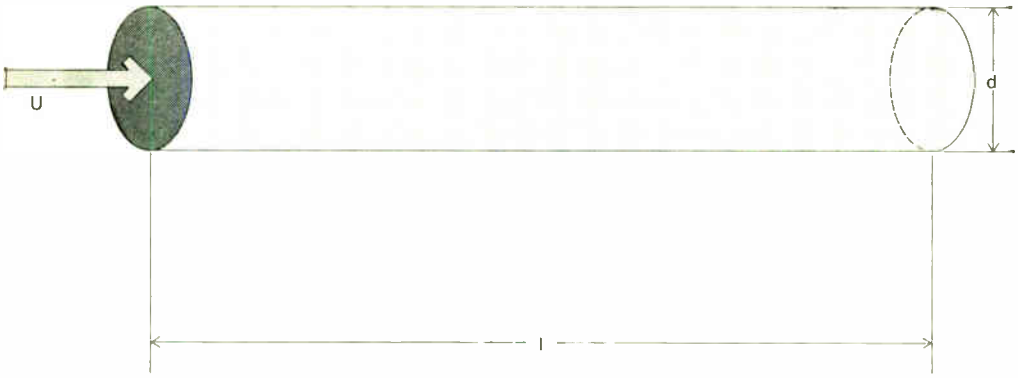


FIGURE 3. Schematic diagram of an EGD converter.

FIGURE 4. Schematic diagram of EGD converter duct.



the gas converter, other problems have been introduced. Operating with a two-phase high-energy fluid is rather difficult, and much effort is at present being exerted on problems such as injection, drift tube design for rapid condensation, and separation of the two-phase fluids. The latter problem arises in the case of the two-phase, two-component cycle under investigation by Elliott at the Jet Propulsion Laboratory. End losses, resulting from the shunt leakage path provided by the fluid at both the upstream and downstream ends of the converter, have been shown to be significant because of the high conductivity of liquid metal. These losses may be considerably reduced in the induction generator by the addition of compensating windings and, in the dc generator, by extending the magnetic field beyond the electrodes. The materials problem still remains, and is a serious one, accentuated by the use of liquid and vaporized metals as the working fluid.

EGD conversion

The operating principle of the EGD converter is similar to that of the Van de Graaff generator, except that a moving gas rather than a moving belt is used to transport the charge carriers. The possibility of achieving power densities of 5 MW/m^3 by employing the greater charge capacity and velocity capabilities of a gas stream was first noted by W. E. Bennett.[8]

Figure 3 shows the EGD converter schematically. A gas is ionized (by a corona discharge, for example) while expanding through a nozzle into a narrow tube (approximately 4 mm in diameter). The heavy, positively charged gas ions are swept down the tube by the gas stream, and as a result a potential develops between the attractor and collector electrodes. This potential may be utilized by placing an external electric load across the electrodes. Unlike the MHD converter, the EGD converter has a high internal impedance, and so generated voltages of 100 kV are typical. The electric energy produced by the converter is derived from the thermodynamic energy of the gas, since work must be done in causing the positively charged atoms to move down the tube against the opposing electric field.

The EGD converter employs electric rather than magnetic fields to provide electromechanical coupling,

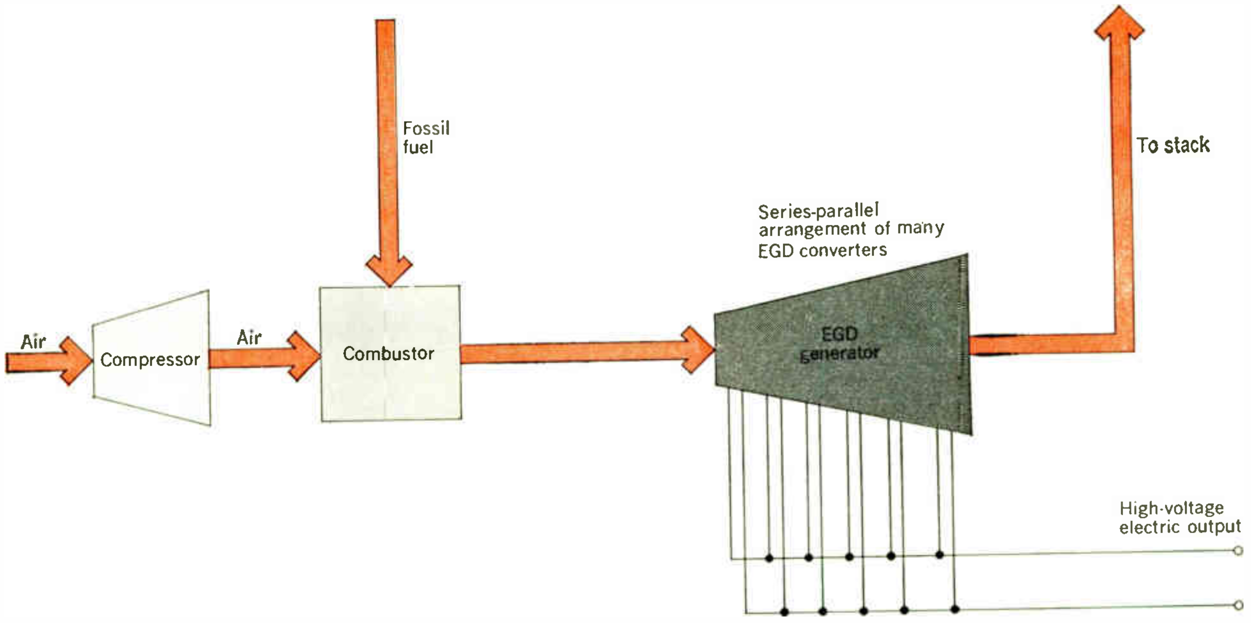


FIGURE 5. Schematic diagram of an EGD–fossil fuel converter system.

and, almost traditionally, such energy converters are viewed with skepticism.[9] This is understandable if both the high charge transport rate and high electrostatic breakdown capabilities of the EGD converter are not recognized.

The following simplified calculation indicates power densities from 1 to 10 MW/m³. Consider the cylindrical model of an EGD duct of length l and diameter d; see Fig. 4. If the average charged-particle concentration is n_i, then the average radial electric flux density at the tube wall D_r may be evaluated, using Gauss's law, as follows:

$$\left(\frac{\pi d^2 l}{4}\right) e n_i = \pi d l D_r = \pi \epsilon d l E_r \qquad (1)$$

where E_r is the average radial electric field intensity at the tube wall. (It is assumed that the channel is slender—that is, $l \gg d$.) Consequently, at breakdown, when $E_r = E_b$ (the breakdown electric field intensity), the average charge density is

$$n_i = \frac{4\epsilon E_b}{ed} \qquad (2)$$

If the average axial velocity of the charge carriers is U, the axial current density at breakdown is

$$J = n_i e U \qquad (3)$$

Substituting Eq. (2) into (3) gives

$$J = \frac{4\epsilon E_b U}{d} \qquad (4)$$

If the tube is designed so that the axial and radial electric field intensities are both equal at breakdown ($E_x = E_r = E_b$), the axial power density at breakdown is

$$p = J E_b = \frac{4\epsilon E_b^2 U}{d} \qquad (5)$$

Upon substituting typical values of $\epsilon = \epsilon_0 = 8.85 \times 10^{-12}$ F/m, $E_b = 3 \times 10^6$ V/m, $U = 65$ m/s, and $d = 4 \times 10^{-3}$ m, Eq. (5) gives a power density of 5.18×10^6 W/m³. Such a value would appear to be conservative when compared with a value of 2.18×10^9 W/m³ arrived at by M. P. Khan[10] for an EGD system employing a 640-m/s gas stream at 30 atmospheres when generating 500 kV.

However, although the power density is large, the output power from a single tube is small. For example, if a maximum terminal voltage of 250 kV is required, the tube length should be $250 \times 10^3/(3 \times 10^6) = 8.3 \times 10^{-2}$ meter. As a result, the active volume, with a tube diameter of 4×10^{-3} meter, would be 1.04×10^{-6} m³, which would result in a power capability of only $1.04 \times 10^{-6} \times 5.18 \times 10^6 = 5.4$ watts.

Friction loss. It is obvious, therefore, that for large-scale power production an EGD system must be composed of many tubes arranged so that the working gas flows through several stages, each composed of numerous tubes in parallel. A consequence, apart from the practical problems of designing a reliable and low cost tube, is the inherent frictional loss. An estimate of the relative significance of this loss may be made by comparing the frictional pressure drop with the EGD body-force pressure drop.

The frictional pressure drop is given by the Darcy equation as

$$\Delta p_f = f \frac{l}{d} \rho \frac{U^2}{2} \qquad (6)$$

where f is the friction coefficient and ρ is the gas density. The relatively low gas velocity of 65 m/s is typical, so that the Reynolds number remains less than 3000 and most of the flow is laminar with a friction coefficient of about 0.025. For an average gas density of 0.3 kg/m³ the frictional pressure drop across a single tube is 330 newtons per square meter.

The EGD body-force pressure drop at breakdown is

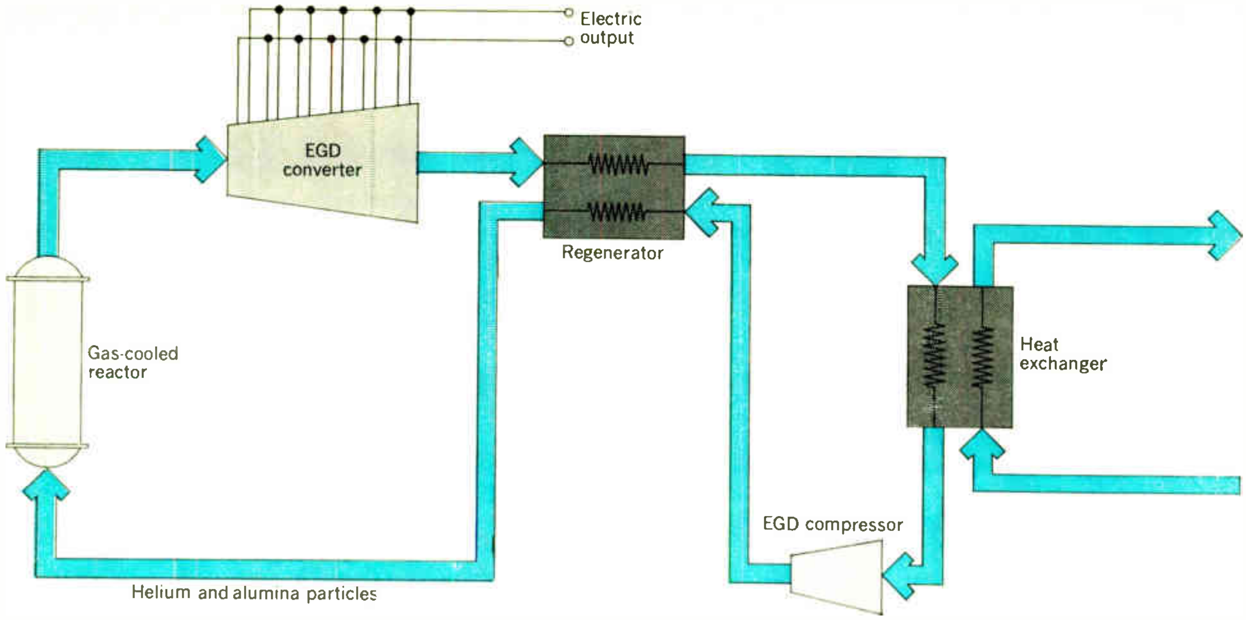


FIGURE 6. Schematic diagram of a closed-cycle EGD converter system.

$$\Delta p_e = e n_i E_b l \tag{7}$$

which results in a gas pressure drop of 6600 N/m² across a single tube. Consequently, when gas velocities are in the range considered, the tube-wall frictional pressure loss is only about 5 percent of the EGD body-force pressure drop. Additional frictional loss—due to electrodes, for example—would, of course, be encountered.

Ion mobility. Effective operation of the EGD converter depends on ensuring that the ions within the transport region of the converter have low mobility. If this requirement is not met, the ions can easily move against the gas flow; then, rather than being swept down the channel to the collector, they are influenced by the electrostatic field and slip upstream to the attractor and are thus lost from the process.[11] To counter the ion slip, A. M. Marks[12] proposed seeding the gas with charged aerosol particles; converters based on this idea have been investigated.[13,14] In such converters the fluid is partially ionized at the nozzle, and as the highly mobile ions enter into the transport region the neutral particles condense about them. As a result, the mobility of the charge carriers is considerably reduced. Marks, Barreto, and Chu[14] conducted a series of tests with air–water and air–ethanol aerosols and measured charge carrier mobilities of about 10^{-6} m²/V·s and subsequently concluded that "mobility effects are truly negligible." Similar results were obtained by Bernard Kahn.[11]

Ion mobility may also be reduced in other ways. In fact, any colloidal-size particles in the range of 10^{-1} to 10 μm appear to be suitable.[15] The fossil-fueled EGD converter relies heavily on the presence of fly ash to reduce the charge carrier level. It has been found experimentally[16] that presumably because of ion attraction to, and interaction with, the ash particles, the ion mobility is reduced to the low value of about 10^{-6} m²/V·s. In other words, the ions formed at the entrance of the transport region move downstream to the collector at essentially the same velocity as that of the neutral gas particles.

Under the influence of the radial field the charge carriers tend to drift toward the walls as they are swept down the tube. The average radial velocity at the walls at breakdown, for an ion mobility of $\mu_i = 10^{-6}$ m²/V·s, is $E_r \mu_i = 3 \times 10^6 \times 10^{-6} = 3$ m/s, which is small in comparison with the axial velocity of 65 m/s. Consequently, only a small fraction of the ions are expected to reach the tube walls during their passage between attractor and collector. Ion deposition can be reduced considerably, if required, by expanding the tubes in the downstream direction, such that

$$\frac{\mu_i E_r}{U} < \frac{\Delta d}{l} \ll 1 \tag{8}$$

where Δd is the change in tube diameter over the tube length l.

EGD power systems. The EGD converter system being developed by Foster Wheeler Corporation and Gourdine Systems[16] is shown schematically in Fig. 5. Air and pulverized coal are burned at a rate of 150 pounds (68 kg) of coal per hour at the relatively high pressure of 30 atmospheres in the combustor and the resultant hot gas is permitted to expand through the series–parallel arrangement of EGD converter tubes made of a dielectric ceramic material, such as beryllium oxide. In the systems under development the gas is ionized by a corona discharge between a needle and attractor electrode at the entrance to the tube. Such a configuration introduces considerable frictional loss and, as a result of this and the fact that only one stage has been used so far, overall efficiencies of only 5 percent have been reported.[17] But it must be kept in mind that the major effort to date has been exerted toward analyzing the high-temperature part of the conversion process rather than in providing an efficiency-optimized system.

Areas of improvement lie in the design of the nozzle and tube configuration, as well as the removal of the needle electrode and the associated support structure from the tube. This may be achieved by redesign of the electrode configuration, or the use of other ion production methods.

Marks, Barreto, and Chu[14] have experimentally demonstrated an 83 percent isentropic efficiency, although an overall efficiency per stage of only 1 percent has been reported due to frictional losses under the turbulent conditions of operation. However, they consider generator efficiencies of 60 percent per stage possible. Daman and Gourdine[16] predict cycle efficiencies of 50 percent for a fossil-fueled system with an inlet gas temperature of 1350°K.

Figure 6 shows a closed-cycle EGD converter system in which a gas-cooled nuclear reactor is used as the heat source. Such a combination would appear particularly appropriate, since both converter and reactor performance is improved by operation at high gas pressure (for reasons of reduced ion mobility and improved heat transfer, respectively). This cannot be said for the MHD–nuclear system, in which conflicting needs for high gas pressure in the reactor and low gas pressure in the converter must be reconciled. Gourdine and his associates plan to test a closed-cycle EGD loop, using helium, seeded with submicrometer-size alumina particles in place of fly ash.

Problem areas. At this early stage of development a number of practical problems are apparent, and others will inevitably arise as development proceeds. However, the critical problems of ion slip and radial dispersion have been essentially solved by the use of aerosols, or dust particles, to reduce the charge carrier mobility. The needle–attractor arrangement for gas ionization is not satisfactory and a simpler electrode configuration, or perhaps a new type of ion source, must be developed, so that both complexity and frictional losses are reduced. The successful development of the EGD tube depends on the ability to manufacture large quantities of them economically.

Corrosion and electrical breakdown problems must certainly be considered. Both would appear to be particularly severe in the fossil-fueled system, where the fly ash accentuates hot gas corrosion and ash deposition on the walls encourages electrical breakdown. Although these problems undoubtedly exist, the materials problems associated with the much hotter gases of the MHD system are not encountered. The fact that most corrosion is found to take place at the needle electrode raises another argument in favor of seeking a different means of ionization, thereby eliminating the electrode.

A most significant potential problem arises in the case of the fossil-fueled system: the possibility of a thin film of conducting material lining the wall of one of the tubes. Although tests on this problem are at present under way at Virginia Polytechnic Institute, it is not yet possible to verify Gourdine's proposition that all of the other tubes would feed current through the film and burn it off. This argument is supported to a certain extent by such an occurrence on high-voltage power transmission lines, where dust films are instantaneously burned from standoff insulators by surface tracking currents.

Until this particular potential problem is satisfactorily examined, the prospects for a fossil-fueled EGD converter are in doubt. However, a closed-cycle nuclear-powered system is always an alternative, whether or not the fossil-fuel contamination and corrosion problems prove insurmountable.

Prospects for EGD. When compared with other direct energy-conversion devices, and in particular with MHD, the EGD converter appears to have several important advantages. The fact that a high gas temperature is not a basic requirement is perhaps the most significant of these advantages. In fact, power may be extracted from the gas until conventional stack temperatures are reached. Consequently, unlike the MHD system, the EGD system need not be used as a topping cycle with a conventional plant but can operate as a complete and independent system. As a result, the need for rotating machines, heat exchangers, and large quantities of cooling water does not exist. Because cooling water requirements are minimal, the system is admirably suited for operation in arid regions, or at a mine head.

Unlike other direct converters, the EGD system generates at transmission-line voltages; in addition, since the generated voltage responds to variations of the ionization rate, ac generation should be possible by running groups of converters back to back, with appropriately modulated ionization sources.

The EGD system is unique in that it promises to generate ac power at transmission-line voltages in a direct process using conventional or nuclear energy sources. Although a considerable amount of development work has yet to be done and a number of problems have yet to be solved, the ultimate goals themselves appear so rewarding that the research effort in this area is certain to be intensified.

REFERENCES

1. Tsu, T. C., "MHD power generation in central stations," *IEEE Spectrum*, vol. 4, pp. 59–65, June 1967.
2. Rosa, R. J., "Shock wave spectroscopy," Thesis, pt. I, Cornell University, 1956.
3. Kerrebrock, J. L., "Conduction in gases with elevated electron temperatures," in *Engineering Aspects of Magnetohydrodynamics*, C. Manual and N. Mather, eds. New York: Columbia University Press, 1962.
4. Satkowski, J. A., "Meeting report on MHD Electric Power Symposium, Salzburg, Austria, 1966," *Nucl. News*, vol. 9, p. 29, Sept. 1966.
5. Brogan, T. R., "MHD power generation," *IEEE Spectrum*, vol. 1, pp. 58–65, Feb. 1964.
6. Petrick, Michael, "Liquid-metal magnetohydrodynamics," *IEEE Spectrum*, vol. 2, pp. 137–151, Mar. 1965.
7. Jackson, W. D., Pierson, E. S., and Porter, R. P., "Design considerations for MHD induction generators," Paper 61, International Symposium on MHD Electric Power Generation, Paris, 1964.
8. Bennett, W. E., "Generation of direct current at high potentials," *Res. Appl. Ind.*, vol. 12, pp. 455–459, Dec. 1959.
9. Fitzgerald, A. E., and Kingsley, C., *Electric Machinery*, 2nd ed. New York: McGraw-Hill, 1961, p. 81.
10. Khan, M. P., "High-voltage electrogasdynamic generators," ASME Paper 64-WA/ENER-11.
11. Kahn, B., "Continuation of the basic study of slender channel electrodynamics," Rept. ARL 65-4, Aerospace Research Laboratories, USAF Office of Aerospace Research, Jan. 1965.
12. Marks, A. M., "Heat–electrical power conversion through the medium of a charged aerosol," U.S. Patent 2 638 555, 1953.
13. Cox, A. L., "Colloidal electrohydrodynamic energy converter," *AIAA J.*, vol. 1, pp. 2491–2497, Nov. 1963.
14. Marks, A., Barreto, E., and Chu, C. K., "Charged aerosol energy converter," *AIAA J.*, vol. 2, pp. 45–51, Jan. 1964.
15. Gourdine, M. C., and Malcolm, D. H., "Prospect for electrogasdynamic power," presented at the Internat'l Conf. on Energetics, Rochester, N.Y., 1965.
16. Daman, E. L., and Gourdine, M. C., "Electrogasdynamic power generation," Paper SM-74/197, Foster Wheeler Corp., Livingston, N.J., May 1966.
17. Yeaple, F. D., "Electrogasdynamics—a bold new power source," *Product Eng.*, vol. 37, pp. 90–92, May 1966.

The fast Fourier transform

A detailed explanation is offered of an algorithm that reduces computer time and allows its user to employ powerful frequency techniques once considered inefficient

E. O. Brigham, R. E. Morrow *LTV Electrosystems, Inc.*

The fast Fourier transform (FFT), a computer algorithm that computes the discrete Fourier transform much faster than other algorithms, is explained. Examples and detailed procedures are provided to assist the reader in learning how to use the algorithm. The savings in computer time can be huge; for example, an $N = 2^{10}$-point transform can be computed with the FFT 100 times faster than with the use of a direct approach.

A computer algorithm, called the fast Fourier transform, has opened new avenues of scientific investigation. Problem-solving techniques once considered impractical are now efficiently implemented by the use of the FFT algorithm. Because of its development, many areas in computing have been completely revolutionized. The FFT procedure for synthesizing and analyzing Fourier series was disclosed in a paper by Cooley and Tukey[1]—a paper that is very subtle and somewhat difficult to understand.

It is the intent here to present a more straightforward development of the FFT algorithm. Before we proceed, however, some basic concepts of the Fourier transform will be examined.

Some basics

For continuous periodic functions of time $f(t)$, a familiar tool for analysis is the Fourier-series representation of the function

$$f(t) = \sum_{n=-\infty}^{\infty} F(n) e^{jn2\pi f_1 t} \tag{1}$$

The period of the function is $T_1 = 1/f_1$ and $F(n)$ is the complex Fourier coefficient, given by

$$F(n) = \frac{1}{T_1} \int_{-T_1/2}^{T_1/2} f(t) e^{-jn2\pi f_1 t}\, dt \tag{2}$$

A similar representation for continuous aperiodic functions of time $x(t)$ is given by the integral

$$x(t) = \int_{-\infty}^{\infty} S(f) e^{j2\pi f t}\, df \tag{3}$$

This expression is frequently written in terms of $\omega = 2\pi f$, as

$$x(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} S(\omega) e^{j\omega t}\, d\omega$$

The complex continuous frequency spectrum of the aperiodic function $S(f)$ is expressed by

$$S(f) = \int_{-\infty}^{\infty} x(t) e^{-j2\pi f t}\, dt \tag{4}$$

The reciprocal relations of (3) and (4) are known as a Fourier-transform pair and $S(f)$ is commonly referred to as the Fourier transform of $x(t)$. If $x(t)$ is a periodic function with period T_1, then the Fourier transform $S(f)$ defined in (4) becomes a sequence of weighted impulse functions at integral multiples of the fundamental frequency f_1. The weights correspond to the coefficients of a Fourier series determined from (2).

For functions of time that zero for negative time, the Fourier transform is closely related to the Laplace transform, which is defined as

$$S(p) = \int_0^{\infty} x(t)e^{-pt}\,dt \qquad (5)$$

Variable p is a complex quantity: $p = \alpha + j\omega$. Thus if the real part of p is zero, the Fourier transform given by (4) and the Laplace transform of (5) are identical.

The Fourier and Laplace transforms are useful in a number of applications. In particular, the solution of differential equations is simplified because either of the transforms converts a differential equation with time as the independent variable into an algebraic equation with p or f as the independent variable. The transforms provide an easy means for relating the input and output variables of linear time-invariant systems encountered in electrical, mechanical, and optical systems.

The Laplace transform is most useful for analytical studies of systems because the transformation yields an analytical function defined in two-dimensional space; the location of the roots of the function in two-dimensional space determines system behavior. The inverse Laplace transform involves a contour integration, in two-dimensional space, that is not readily adapted to numerical methods. On the other hand, the Fourier transform yields a complex function defined in a one-dimensional frequency space; consequently, the inverse transformation is easily adapted to numerical methods. The Fourier transform is superior to the Laplace transform for the analysis of physical data because numerical methods and a digital computer are generally used for this purpose.

One Fourier-transform property having application in the analysis of linear time-invariant systems is that the transform of the convolution of two functions is equal to the product of the transforms of the individual functions. To be specific, consider two time functions $x_1(t)$ and $x_2(t)$ having Fourier transforms $S_1(f)$ and $S_2(f)$ given by (4); the convolution $x_3(t)$ of $x_1(t)$ and $x_2(t)$ is

$$x_3(t) = \int_{-\infty}^{\infty} x_1(\tau)x_2(t - \tau)\,d\tau = x_1(t) * x_2(t)$$

The Fourier transform of $x_3(t)$ is given by

$$S_3(f) = S_1(f)S_2(f)$$

One should also note that multiplication in the time domain corresponds to convolution in the frequency domain.

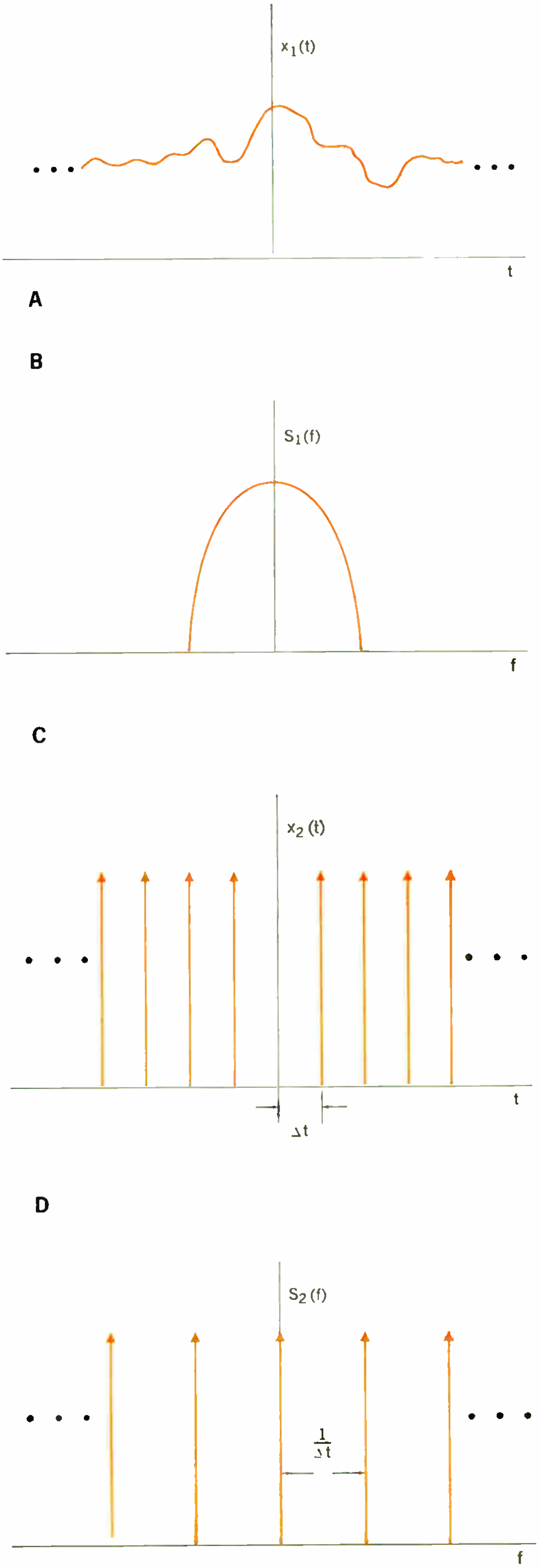
Another application of the Fourier transform is the calculation of power spectra. A power spectrum is defined as a Fourier transformation of the autocorrelation function. For random functions of time the autocorrelation function is expressed as

$$\varphi(t) = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} x(\tau)x(\tau + t)\,d\tau$$

The power spectrum is the Fourier transform of $\varphi(t)$.

Because the Fourier transform is indeed a powerful tool of analysis, it is not surprising that a search was begun to establish techniques to compute the Fourier transform numerically. The discrete Fourier transform therefore evolved, but it was considered impractical until the development of the fast Fourier transform.

FIGURE 1. Fourier transform pairs.



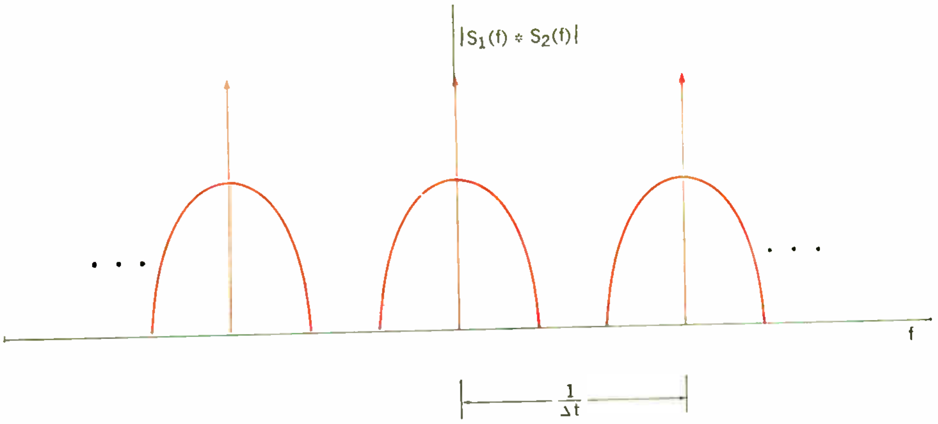


FIGURE 2. Fourier transform of a sampled time function.

Discrete Fourier transform

The relationship between the Fourier transform of continuous and sampled time functions can be established by considering $x_1(t)$ and its Fourier transform $S_1(f)$, illustrated in Figs. 1(A) and (B). One can regard the sampling of $x_1(t)$ as the multiplication of $x_1(t)$ by function $x_2(t)$, an infinite sequence of impulse functions of Fig. 1(C); the Fourier transform of $x_2(t)$ is given in Fig. 1(D). Recall that the multiplication–convolution process forms a Fourier transform pair; therefore, if $x_1(t)$ and $x_2(t)$ are multiplied, $S_1(f)$ and $S_2(f)$ are convolved, yielding the function shown in Fig. 2. The Fourier transform of a sampled time function, from Fig. 2, is then a periodic function of period $1/\Delta t$, where each period contains complete information of the frequency spectrum of $x_1(t)$.

When it is desired to compute the discrete Fourier transform with digital machines, only a finite number of discrete samples of both the time function and the spectrum can be considered. The preceding illustrations apply now heuristically, except that only a sampled version of the periodic spectrum of Fig. 2 can be realized.

In the sampled-data case, the Fourier transform pair given in Eqs. (3) and (4) for N samples becomes

$$S(f_n) = \Delta t \sum_{k=0}^{N-1} x(t_k) e^{-j2\pi f_n t_k} \qquad n = 0, \pm 1, \ldots, \pm N/2$$

$$x(t_k) = \Delta f \sum_{n=-N/2}^{N/2} S(f_n) e^{j2\pi f_n t_k} \qquad k = 0, 1, \ldots, N-1 \qquad (6)$$

If we let $t_k = k\Delta t$, $f_n = n\Delta f$, and if we note that $\Delta t = T/N$ and $\Delta f = 1/T$, Eq. (6) becomes

$$S(n) = \Delta t \sum_{k=0}^{N-1} x(k) e^{-j2\pi(nk)/N} \qquad n = 0, 1, \ldots, N-1$$

$$x(k) = \Delta f \sum_{n=0}^{N-1} S(n) e^{j2\pi(nk)/N} \qquad k = 0, 1, \ldots, N-1 \qquad (7)$$

where argument n takes on the values $0, 1, \ldots, N-1$, rather than $0, \pm 1, \ldots, \pm N/2$. This substitution in no way alters the expression; it is done to simplify the computational procedure. Term $n = N/2$ corresponds to the *aliasing* or *Nyquist folding* frequency.

Computer evaluation of the first equation of pair (7) is the subject of this article. For computational purposes, the equation can be more easily represented in matrix form as

$$[S(n)] = [W^{nk}][X_0(k)] \qquad (8)$$

where $[S(n)]$ and $[X_0(k)]$ are $N \times 1$ column matrices and $[W^{nk}]$ is an $N \times N$ matrix with

$$W = e^{-j2\pi/N}$$

Scaling term Δt will be eliminated for clarity of presentation and subscript zero added to vector $[X(k)]$ for continuity of notation in the remainder of the article.

Consider a simple example of performing the computation indicated by Eq. (8). If we choose the number of sample points $N = 4$, Eq. (8) becomes

$$\begin{bmatrix} S(0) \\ S(1) \\ S(2) \\ S(3) \end{bmatrix} = \begin{bmatrix} W^0 & W^0 & W^0 & W^0 \\ W^0 & W^1 & W^2 & W^3 \\ W^0 & W^2 & W^4 & W^6 \\ W^0 & W^3 & W^6 & W^9 \end{bmatrix} \begin{bmatrix} x_0(0) \\ x_0(1) \\ x_0(2) \\ x_0(3) \end{bmatrix} \qquad (9)$$

In general, execution of (9) requires N^2 complex (W is complex) multiplications and additions.

The fast Fourier transform owes its success to the reduction of the number of complex multiplications and additions. The following discussion presents, on an intuitive level, how the reduction is accomplished. At first reading, do not question the reasoning behind the algorithm, but understand its results.

Intuitive development of the FFT

In using the FFT, it is convenient to choose the number of sample points of $x_0(t)$ according to the relation $N = 2^\gamma$, where γ is an integer. In the preceding example that yielded (9), $N = 4 = 2^\gamma = 2^2$; because $\gamma = 2$, then the FFT could be applied. The first step is to write the matrix $[W^{nk}]$ in (9) as

$$\begin{bmatrix} S(0) \\ S(1) \\ S(2) \\ S(3) \end{bmatrix} \begin{matrix} = \\ = \\ = \\ = \end{matrix} \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & W^1 & W^2 & W^3 \\ 1 & W^2 & W^0 & W^2 \\ 1 & W^3 & W^2 & W^1 \end{bmatrix} \begin{bmatrix} x_0(0) \\ x_0(1) \\ x_0(2) \\ x_0(3) \end{bmatrix} \tag{10a}$$

Equation (10a) was derived from (9) by using the relation $W^{nk} = W^{nk \bmod N}$. For example, if $N = 4$, $n = 2$, and $k = 3$, then $nk = 6$ and $nk \bmod N = 2$. Recall that $nk \bmod N$ is the remainder upon division of nk by N; hence,

$$W^{nk} = \exp\left[\frac{-j2\pi}{4}(6)\right] = \exp[-j3\pi]$$

$$= W^{nk \bmod N} = \exp\left[\frac{-j2\pi}{4}(2)\right] = \exp[-j\pi]$$

In the second step, (10a) is rewritten as

$$\begin{bmatrix} S(0) \\ S(2) \\ S(1) \\ S(3) \end{bmatrix} = \begin{bmatrix} 1 & W^0 & 0 & 0 \\ 1 & W^2 & 0 & 0 \\ 0 & 0 & 1 & W^1 \\ 0 & 0 & 1 & W^3 \end{bmatrix} \begin{bmatrix} 1 & 0 & W^0 & 0 \\ 0 & 1 & 0 & W^2 \\ 1 & 0 & W^2 & 0 \\ 0 & 1 & 0 & W^2 \end{bmatrix} \begin{bmatrix} x_0(0) \\ x_0(1) \\ x_0(2) \\ x_0(3) \end{bmatrix} \tag{10b}$$

The method of factorization will be explained later. The value of W^0 is equivalent to unity; both the quantity W^0 and 1 are used in (10b) to develop a generalized final result. Equation (10b) may be verified by multiplying the two square matrices and realizing that the resultant square matrix is equal to $[W^{nk}]$ in (10a), with the exception that rows 1 and 2 have been interchanged. This interchange has been accounted for in (10b) by rewriting the column vector $[S(n)]$; let the row-interchanged vector be denoted by

$$\overline{[S(n)]} = \begin{bmatrix} S(0) \\ S(2) \\ S(1) \\ S(3) \end{bmatrix}$$

Having accepted the fact that (10b) will yield correct computed results, although they are scrambled, one should examine now the number of complex multiplications and additions represented by the equation. First, let

$$\begin{bmatrix} x_1(0) \\ x_1(1) \\ x_1(2) \\ x_1(3) \end{bmatrix} = \begin{bmatrix} 1 & 0 & W^0 & 0 \\ 0 & 1 & 0 & W^0 \\ 1 & 0 & W^2 & 0 \\ 0 & 1 & 0 & W^2 \end{bmatrix} \begin{bmatrix} x_0(0) \\ x_0(1) \\ x_0(2) \\ x_0(3) \end{bmatrix} \tag{11}$$

that is, column vector $[X_1(k)]$ is equal to the multiplication of the two matrices on the right in (10b). Element $x_1(0)$ is determined by one complex multiplication and one addition

$$x_1(0) = x_0(0) + W^0 x_0(2) \tag{12}$$

It is realized that $W^0 = 1$ and a multiplication is not necessary; in order to develop a generalized result, however, this will be considered as one multiplication. Element $x_1(1)$ is also determined by one complex multiplication and addition. One complex addition is all that is required for finding $x_1(2)$. This follows from the fact that $W^0 = -W^2$; hence,

$$x_1(2) = x_0(0) + W^2 x_0(2)$$

$$= x_0(0) - W^0 x_0(2)$$

where the complex multiplication $W^0 x_0(2)$ has already been performed in the calculation of $x_1(0)$. By the same reasoning, $x_1(3)$ is found by only one complex addition and no multiplications. Vector $[X_1(k)]$ is therefore determined by the use of four additions and two multiplications.

Let us continue by computing

$$\begin{bmatrix} S(0) \\ S(2) \\ S(1) \\ S(3) \end{bmatrix} = \begin{bmatrix} 1 & W^0 & 0 & 0 \\ 1 & W^2 & 0 & 0 \\ 0 & 0 & 1 & W^1 \\ 0 & 0 & 1 & W^3 \end{bmatrix} \begin{bmatrix} x_1(0) \\ x_1(1) \\ x_1(2) \\ x_1(3) \end{bmatrix} \tag{13}$$

As before, $S(0)$ is determined by one multiplication and addition

$$S(0) = x_1(0) + W^0 x_1(1)$$

Because $W^0 = -W^2$, element $S(2)$ is found from one addition. By similar reasoning, $S(1)$ is determined by one complex multiplication and addition and $S(3)$ by only one addition. Vector $[S(n)]$ has been computed by a total of $N\gamma/2 = 4$ complex multiplications and $N\gamma = 8$ complex additions; the computation of (9) required $N^2 = 16$ complex multiplications and additions. Obviously, for large values of N the savings become huge and can actually approach 99 percent.

The Cooley–Tukey FFT algorithm can then be considered as a method of factoring an $N \times N$ matrix into γ $N \times N$ ($N = 2^\gamma$) matrices such that each of the new factored matrices has the special property of minimizing the number of complex multiplications and additions. Referring to the previous example, it is seen that the reduction of multiplications and additions is accomplished by the zero terms that were introduced by matrix factoring.

The scheme of matrix factoring does introduce one discrepancy, however; recall that the computation of (10b) yielded $\overline{[S(n)]}$ instead of $[S(n)]$

$$\overline{[S(n)]} = \begin{bmatrix} S(0) \\ S(2) \\ S(1) \\ S(3) \end{bmatrix} \quad \text{instead of} \quad [S(n)] = \begin{bmatrix} S(0) \\ S(1) \\ S(2) \\ S(3) \end{bmatrix}$$

This rearrangement is inherent in the optimum matrix factoring process and is a relatively minor problem because we can easily generalize a scheme to rearrange vector $\overline{[S(n)]}$ for obtaining $[S(n)]$. The rearrangement procedure can be explained as follows: Rewrite vector $[S(n)]$ computed in (9) by replacing argument n with its binary equivalent

$$\begin{bmatrix} S(0) \\ S(1) \\ S(2) \\ S(3) \end{bmatrix} \quad \text{becomes} \quad \begin{bmatrix} S(00) \\ S(01) \\ S(10) \\ S(11) \end{bmatrix} \tag{14}$$

Observe the result if the binary arguments of (14) are flipped or bit-reversed; that is, 01 becomes 10, 10 becomes 01, etc. Then

$$[S(n)] = \begin{bmatrix} S(0) \\ S(1) \\ S(2) \\ S(3) \end{bmatrix} \quad \begin{matrix} \text{flips} \\ \text{to} \end{matrix} \quad \begin{bmatrix} S(00) \\ S(10) \\ S(01) \\ S(11) \end{bmatrix} = \overline{[(Sn)]}$$

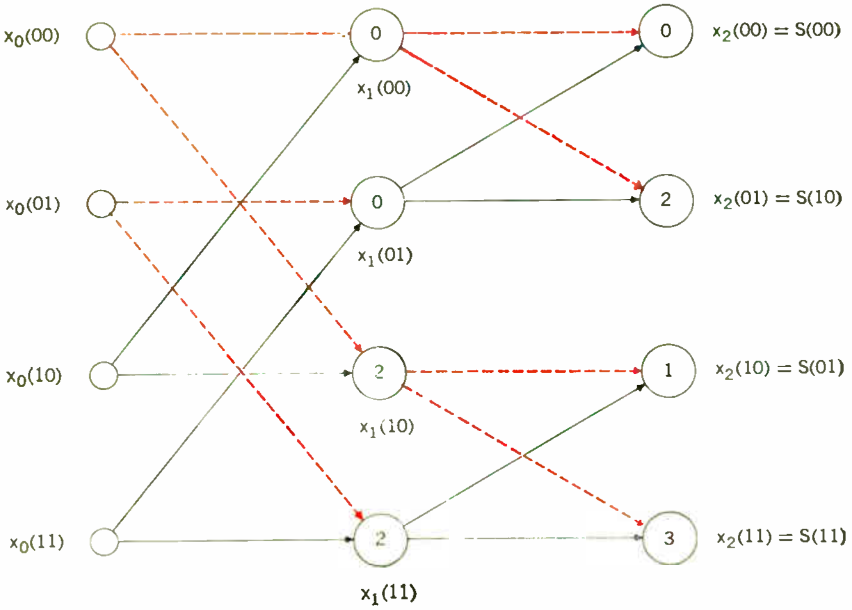


FIGURE 3. Tree-graph representation of factored matrices.

The scrambled vector $[\bar{S}(n)]$ is merely $[S(n)]$ with the binary argument flipped. To illustrate this point further, suppose $N = 8$; the determination of vector $[\bar{S}(n)]$ by matrix factorization yields

$$[\bar{S}(n)] = \begin{bmatrix} S(000) \\ S(100) \\ S(010) \\ S(110) \\ S(001) \\ S(101) \\ S(011) \\ S(111) \end{bmatrix}$$

$$= \begin{bmatrix} S(0) \\ S(4) \\ S(2) \\ S(6) \\ S(1) \\ S(5) \\ S(3) \\ S(7) \end{bmatrix} \quad \text{instead of} \quad \begin{bmatrix} S(000) \\ S(001) \\ S(010) \\ S(011) \\ S(100) \\ S(101) \\ S(110) \\ S(111) \end{bmatrix} = [S(n)]$$

Therefore, by bit-reversing the argument of vector $[\bar{S}(n)]$, one knows exactly where each component of the scrambled vector $[\bar{S}(n)]$ actually belongs.

An obvious question at this stage in the development of the FFT algorithm is "How does one obtain the general form of the factored matrices for an $N \times N$ matrix?" To answer this question, let us continue the example for $N = 4$ and convert (10b) to the tree graph of Fig. 3. The sampled data $[X_0(k)]$ are represented by a vertical column of nodes on the left of the graph; argument k has been replaced by its binary equivalent. The center vertical column of nodes corresponds to vector $[X_1(k)]$ computed in (11) and the right-hand column of nodes represents vector $[X_2(k)] = [\bar{S}(n)]$; see Eq. (13). Note that each node is entered by a dashed and a solid line; within each node is an integer.

The solid line brings a quantity from one of the nodes in a previous column, multiplies the quantity by W^p, where p is the integer in the circle, and the product is added to the quantity brought by the dashed line. If we were at node $x_1(00)$, then

$$x_1(00) = x_0(00) + W^0 x_0(10) \tag{15}$$

Equation (15) is just (12) with the arguments expressed as binary numbers. A similar procedure is used for expressing each of the remaining nodes.

To summarize, Fig. 3 is a graph of the computational procedure that was used in the factored-matrices representation of (10). Further, γ vertical arrays or columns are computed; that is, each vertical column computed corresponds to one of the factored matrices.

Generalized graph construction

A general method of establishing a graph of the form of Fig. 3 for any $N = 2^\gamma$ will be formulated by the following set of rules:

1. Assume N sample values of the time function $x_0(t)$ constitute the first vertical array of nodes. Let the array of nodes or vector be denoted by $[X_0(k)]$, where $k = 0, 1, \ldots, N - 1$ represent the sample times or address (location) of function $x_0(t)$; argument k is expressed as a binary number. This binary number determines the location of node $x_0(k)$; see Fig. 3. The binary arguments or locations are expressed by γ bits; for $N = 4$, each address is expressed by $\gamma = 2$ bits.

The other arrays $[X_l]$ are drawn successively to the right, and the nodes in each array are addressed as binary numbers according to the previous discussion. Nodes or locations on the same horizontal level have the same binary address. At each node, a circle is drawn and a number is written in this circle, as explained by rule 2.

2. The number in the circle of the kth node in the lth array (note that the left-most array is the 0th array) is found by (a) writing the binary number k, (b) scaling

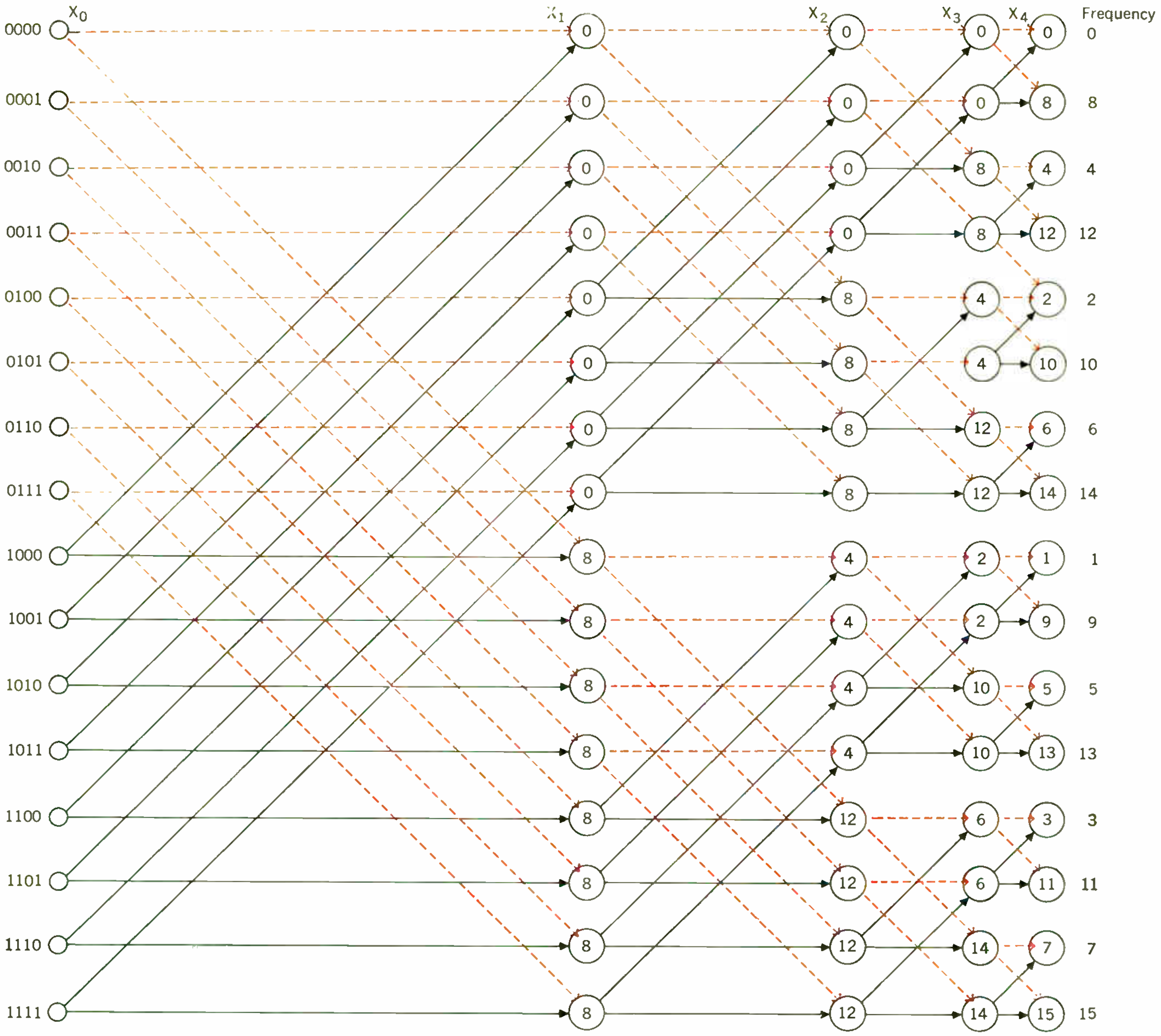


FIGURE 4. Tree graph for N = 16

or sliding this number ($\gamma - l$) places to the right and filling in the newly opened bit positions on the left by zeros, and (c) reversing the order of the bits.

For example, referring to Fig. 3, let $\gamma = 2$, $k = 2$, and $l = 1$; then k in binary is 10. Scale $\gamma - l = 2 - 1 = 1$ to the right, that is 01, and then reverse the order of bits yielding 10 or integer 2.

3. For generality, let the binary representation of k be $k_{\gamma-1} \ldots k_1k_0$. For example, if $\gamma = 2$ and $k = 2$, then $k_0 = 0$ and $k_1 = 1$; therefore, $k_1k_0 = 10$. This additional nomenclature is needed for the following general statement: In the lth array, node k (in binary form $k_{\gamma-1} \ldots k_1k_0$) has a solid line drawn to it from a node in the ($l - 1$)th array. The address of the node in the ($l - 1$)th array is the same as node k, except that bit $k_{\gamma-l}$ must be a one. The dashed line comes from a node in the ($l - 1$)th array whose address is the same, but bit $k_{\gamma-l}$ must be a zero.

For example, let $\gamma = 2$, $l = 1$, and $k = 1$; k in binary is $k_1k_0 = 01$. The bit in question is $k_{\gamma-1} = k_1$. The solid line will come from address (11) in the 0th array; similarly, the dashed line will come from address (01) in the 0th array.

The preceding rules are sufficient to sketch the tree graph for computing Fourier transform values for any value of $N = 2^\gamma$. To clarify these rules and to develop another tree graph for further discussion, let us sketch the graph for $N = 16$ ($\gamma = 4$). By rule 1, the 16 data points form the left vertical array denoted by $[X_0]$ in Fig. 4; the location or address of each point is described by a binary number having $\gamma = 4$ bits. Because $\gamma = 4$, four additional arrays $[X_l]$ are drawn successively to the right: that is, $[X_1]$, $[X_2]$, $[X_3]$, and $[X_4]$.

If we apply rule 2, integers in the circles at each node are determined. For example, for array $l = 3$, mode 8 (the left-most array is array $l = 0$), the integer in the node is found by writing 8 in binary as 1000; scaling it $(\gamma - l) = 1$ places to the right yields 0100; and reversing the order of the bits yields 0010. The integer 2 therefore appears in the circle of the node in question.

Finally, by rule 3, the origin of the solid and dashed lines to each node is determined. In Fig. 4, consider array 1, node 8. By rule 3, a solid line emanates from the node in array $l = 0$ whose location is the same as 1000, except that bit $k_{\gamma-1} = k_3$ must be one (location 1000). The dashed line comes from a node in array $l = 0$ whose location is the same as 1000 except that bit k_3 is zero, or location 0000. Similar reasoning can be employed to determine the origin of all the dashed and solid lines shown in Fig. 4.

Note that node location 1000 in array $l = 1$ is only affected by node locations 0000 and 1000 in array $l = 0$. Node locations 0000 and 1000 in the 0th array only affect one other node in the first array, node location 0000. In general, there exist two nodes in array 1 that are affected by the same pair of nodes in array 0; no other nodes in 1 are affected by either of the two nodes in array 0. This statement implies that there is a savings of half the number of multiplications indicated by the tree graph.

Examining further the node pair 0000 and 1000 in array 1, we see that the solid line entering the pair stems from the same node in array 0 and that the dashed line follows a similar pattern. A solid line going to a node implies the quantity brought by the solid line is to be multiplied by W raised to the integer power in the node; the integers in nodes 0000 and 1000 differ by $N/2$. Because $W^{N/2} = (e^{-j2\pi/N})^{N/2} = -1$, then $W^{\beta} = -W^{\beta+N/2}$, where β is integer valued. For the two nodes in question, therefore, one multiplication is saved since the solid line entering the two nodes stems from the same node in array 0.

Each node in arrays $l = 1, 2, 3$, and 4 has associated with it a node to which all the foregoing arguments apply; in each array half the number of multiplications implied by the nodes can be saved. This argument is just a tree-graph explanation of the multiplication savings presented in the factored matrices discussed earlier.

The Fourier transform values desired are found in array $l = 4$ in Fig. 4. As indicated before, the location or argument of these transform values is scrambled. For example, the transform component located in 0001 is actually the frequency component $S(1000)$. This is determined by bit-reversing the location, where 0001 flips to 1000. The address of array $[X_4]$ must be bit-reversed before the final transform values are obtained.

Verification of tree graphs

To verify a tree graph, such as Fig. 4, it is necessary to show that the γth array corresponds to those values obtained from

$$S(n) = \sum_{k=0}^{N-1} x_0(k) e^{-j2\pi nk/N} \qquad n = 0, 1, \ldots N-1 \qquad (16)$$

From (16), each value of transform $S(n)$ is a weighted sum of all the discrete signal values, $x_0(k)$. Also, from Fig. 4, each node in the γth array is a weighted sum of all points in the $[X_0]$th array. To verify the FFT it is necessary to show that the weights in the tree graph and (16) are in correspondence.

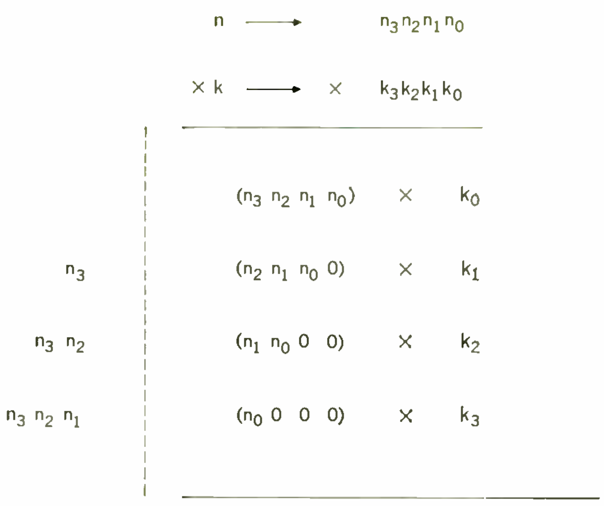


FIGURE 5. Binary computation of nk mod N.

To show this correspondence, first examine the weight contributed by each signal value $x_0(k)$ in (16); each sample contributes

$$e^{-j2\pi nk/N} = W^{nk} = W^{nk \bmod N}$$

It is of interest to indicate the binary computation of $nk \bmod N$. Let the binary representation of n and k be $n \rightarrow n_3n_2n_1n_0$ and $k \rightarrow k_3k_2k_1k_0$, where the notation is exactly as previously discussed. Note that only four bits were assumed in the binary representation; that is, γ was assumed to be 4. In Fig. 5 the binary computation of $nk \bmod N$ is shown; the peculiar form of writing the multiplication is necessary for illustrating further points to be developed. The terms to be left of the dashed line do not contribute to the sum mod N. For example, consider $n = 13$, $k = 5$, and $\gamma = 4$:

$$\begin{array}{rcl}
 & n = 13 \rightarrow & 1101 \\
 & \times\ k = 5 \rightarrow & \times\ 0101 \\
\hline
 & & (1101) \times 1 \\
 & 1 & (1010) \times 0 \\
 & 1\ 1 & (0100) \times 1 \\
 & 1\ 1\ 0 & (1000) \times 0 \\
\hline
 & 1\ 0\ 0 & 0001 \qquad 65 \bmod 16 = 1
\end{array}$$

If we use the binary representation of the computation of $nk \bmod N$, W^{nk} can be factored as

$$\begin{aligned} W^{nk} &= W^{nk \bmod N} \\ &= W^{k_3(n_0000)}\, W^{k_2(n_1n_000)}\, W^{k_1(n_2n_1n_00)}\, W^{k_0(n_3n_2n_1n_0)} \qquad (17) \end{aligned}$$

It will be shown that a tree graph corresponds to the factoring of W^{nk} in (17).

Examination of Fig. 4 shows that node $x_0(k)$, the kth time sample, is connected to any of the spectrum nodes $x_4(k)$ by γ lines. For example, $x_0(0000)$ and $x_4(0000)$ are connected only by four horizontal dashed lines; these γ lines correspond to the factoring of W^{nk} in (17). The solid or dashed characteristics of the lines depend on the value of k_i. If $k_i = 1$, the line is solid; for $k_i = 0$, it is

Historical evolution of the fast Fourier transform

The beginnings of the modern-day fast Fourier transform dates back to 1903 when Runge[2] described a computational technique for 12- and 24-point Fourier transforms. Runge's scheme was not generalized until 1942 when Danielson and Lanczos[3] published a method for the optimal computation of $N = 2^k$-point Fourier transforms; this efficient method, however, passed unnoticed to interested researchers.

Another line of development was introduced in 1937 by Yates,[4] whose algorithm efficiently computed the interaction of 2^n factorial experiments; the form of the algorithm differed from that of Danielson and Lanczos.[3] Davies and others[5] extended Yates' method of 3^n experiments. Good[6] later extended this approach to general factorial experiments and at the same time outlined a procedure for the computation of N-point Fourier transforms where $N = r_1 r_2 \ldots r_m$, that is, composite with mutually prime factors. This restriction of N was removed by Cooley and Tukey[1] and the first computer program to compute the FFT was probably written at this time. Still later a different form of the algorithm was introduced by Gentleman and Sande.[7] The Cooley–Tukey paper sparked a renewed interest in the Fourier transform as an analysis tool.

Stockham[8] disclosed the efficiency of the fast Fourier transform as applied to convolution and correlation processing. Because of the high interest in the fast Fourier transform, the entire June 1967 issue of IEEE TRANSACTIONS ON AUDIO AND ELECTROACOUSTICS was devoted to the FFT.

dashed. This is consistent with the previously defined rule that a solid line entering a node implies a multiplication by W raised to the integer in that node.

Assume we are to compute the Fourier transform value with the argument $n_3n_2n_1n_0$; this value will end up in position $n_0n_1n_2n_3$. Let us start in the 0th array at position $k_3k_2k_1k_0$ and proceed by the solid and dashed lines to location $n_0n_1n_2n_3$ (see Fig. 4). One takes the following positions in the various arrays (an example is indicated in parentheses; start at location 0111 and head for 0011).

Array	Position	Power of W	
0	$k_3k_2k_1k_0$ (0111)		
1	$n_0k_2k_1k_0$ (0111)	n_0000	(0000)
2	$n_0n_1k_1k_0$ (0011)	n_1n_000	(0000)
3	$n_0n_1n_2k_0$ (0011)	$n_2n_1n_00$	(1000)

The power of W denoted by the contents of the circle at each node is given in the third column and is determined by rule 2 (address scaled $\gamma - l$ places to the right with the bits reversed). These weights then correspond to the terms in (17) and the correspondence between Fig. 4 and (17) is complete. The tree-graph representation and the rules presented here are essentially derived from an unpublished memorandum by C. M. Rader of the M.I.T. Lincoln Laboratory.

Conclusions

The value of the fast Fourier transform is in the reduction of computer time in evaluating the discrete Fourier transform. An N-point transformation by the direct method requires a time proportional to N^2 whereas the FFT requires a time proportional to $N \log_2 N$. The approximate ratio of FFT to direct computing time is given by

$$\frac{N \log_2 N}{N^2} = \frac{\log_2 N}{N} = \frac{\gamma}{N}$$

where $N = 2^\gamma$. For example, if $N = 2^{10}$, the FFT requires less than 1/100 of the normal computing time.

Convolution and correlation, both extremely useful mathematical techniques in time-series analysis, are usually computed digitally by forming the lagged product

$$\frac{1}{N} \sum_{\tau=0}^{N-1} x_1(t - \tau) x_2(\tau)$$

This calculation consumes considerable computer time with conventional techniques. Using the FFT, one can reduce computing time as follows: First, using the FFT, $x_1(t)$ and $x_2(t)$ are Fourier-transformed, yielding $S_1(f)$ and $S_2(f)$. Terms $S_1(f)$ and $S_2(f)$ are then multiplied and the resultant is inverse-Fourier-transformed by use of the FFT. Stockham[8] showed that for $N \approx 28$, the FFT method is faster than the conventional lagged-products approach. For $N = 4096$, Stockham estimates that the FFT technique is 80 times faster.

General areas in which the FFT is finding successful application include digital signal enhancement, image enhancement in character recognition, spatial filtering, real-time digital speech analysis, power spectra estimation, and system simulation. In fact, the computer algorithm has opened new avenues of scientific investigation never before considered practical because of exorbitant computing times. In essence, the scientific analyst now has opened to him all those frequency-domain analysis techniques once considered inefficient.

REFERENCES

1. Cooley, J. W., and Tukey, J. W., "An algorithm for the machine calculation of complex Fourier series," *Math. Comput.*, vol. 19, pp. 297–301, Apr. 1965.

2. Runge, C., *Z. Math. Phys.*, vol. 48, p. 443, 1903.

3. Danielson, G. C., and Lanczos, C., "Some improvements in practical Fourier analysis and their application to X-ray scattering from liquids," *J. Franklin Inst.*, vol. 233, pp. 365–380 and 435–452, Apr. 1942.

4. Yates, F., "The design and analysis of factorial experiments," Commonwealth Agriculture Bureaux, Farnam Royal, Bucks., England, 1937.

5. Box, G. E. P., Connor, L. R., Cousins, W. R., Davies, O. L. (ed.), Himsworth, F. R., and Sillitto, G. P., *The Design and Analysis of Industrial Experiments*. London: Oliver & Boyd, 1954, pp. 363–366.

6. Good, I. J., "The interaction algorithm and practical Fourier analysis" *J. Roy. Statist. Soc.*, ser. B, vol. 20, pp. 361–372, 1958.

7. Gentleman, W. M., and Sande, G., "Fast Fourier transforms for fun and profit," *1966 Fall Joint Computer Conference, AFIPS Proc.*, vol. 29, pp. 563–578.

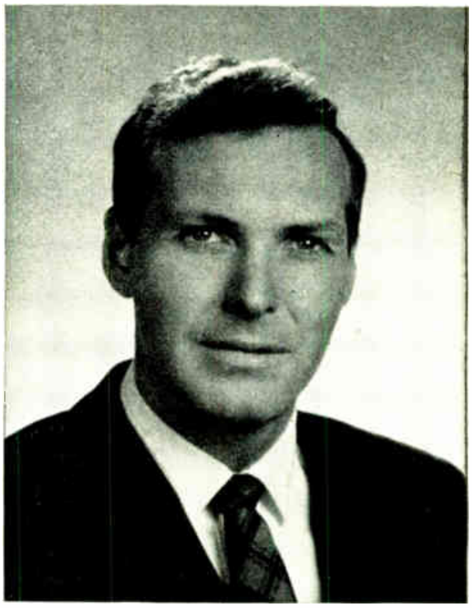
8. Stockham, T. G., "High-speed convolution and correlation," *1966 Joint Computer Conference, AFIPS Proc.*, vol. 28, pp. 229–233.

Cooperation of universities and utilities for the education of power-system engineers

The need of the power utilities for competent engineers with specialized training is alarmingly acute. The prognosis looks grim, because the engineering graduates are turning away from the power industry to enter other fields

E. A. Erdelyi, F. S. Barnes *University of Colorado*

E. A. Erdelyi



F. S. Barnes

The growing complexity of the power industry requires an increased influx to the utilities of highly trained engineers on the B.S., M.S., and Ph.D. levels. These men must be specialists in the power field. Ironically, the number of engineers available to the electric utilities is rapidly declining. Few colleges and universities offer specialized courses in the power field. Few professors teach the necessarily specialized courses. And, as a result, few graduates are either interested in or qualified to enter the power industry. The whole problem seems to be money.

There has been long-standing disagreement among utilities' representatives and educators concerning the problem of educating engineers for the power field.[1] Among educators themselves there is little accord as to methods of training young engineers for a career with the utilities, although some may concur in ignoring utilities entirely.

The present confusion of views and disinterest provide the authors' motive to illustrate some of the problems of training utilities' engineers, and to offer possible solutions. Among the problems are that

1. Specialized training of engineers desiring to work in the power utilities is available at very few schools.
2. Many professors teaching power courses are retiring or transferring to more rewarding fields, thus further diminishing available instruction.
3. Very few new members with interests in power are being added to engineering school faculties.
4. Talented graduates available to utilities are already in short supply; and the demand is becoming greater.

Increased enrollment vs. curricula

University enrollments are rapidly rising, and soon nearly half of the future high school graduates will go on to college. Unfortunately, engineering enrollments are by no means increasing proportionately. Concerned educators are discussing, at length, the many reasons for this relative drop in engineering enrollment. Among these reasons are the following:

1. Engineering curricula are known to be difficult and to require mathematics, not necessarily a popular subject in high school.
2. High school students know very little about engineering as a vocation.
3. Engineering does not seem to have the "humanitarian" attractions of medicine or law.
4. There are easier and more remunerative ways to make a good living; therefore the economic drive to study for the engineering profession is not as great as it was in the past.

The result of these factors is pressure on the engineering colleges not to make the engineering curriculum any more difficult or longer than programs in physics or mathematics, and to include some courses with alluring titles. These are demands imposed, as it were, from the outside; yet they need to be met. At the same time these pressures are occurring on the undergraduate level, another set of problems is caused by the increase in graduate enrollments and continuing education of practicing engineers, problems that again affect the undergraduate program.

Before World War II, only about 5 percent of the graduating seniors continued to advanced studies. Now the number is about 30 percent; and this growth of our graduate programs has, in turn, forced engineering colleges to include more scientific and analytic material in undergraduate programs. Concurrent with the growth of graduate training has been the increased demand for continuing education of practicing engineers—resulting in the addition of nondegree programs, and a need for graduate course work available to part-time students working in industry. (Most of this graduate work, it should be noted, leads to master's degrees that do not require a thesis.) The demand for graduate and continuing education programs has been impelled by the ever-increasing, rapid developments of new fields of technology. New developments in fields such as solid-state technology, computing, optics, and bioengineering are forcing many practicing engineers to study subjects that were not included in earlier programs.[2] These new technologies are also continually forcing their way into the undergraduate program at the expense of more traditional materials. Course offerings in computer programming, communication theory, probability theory, and solid-state physics are imperative additions to the undergraduate curriculum. The total amount of material in the curriculum, however, represents a smaller fraction of the present-day available technical information that a graduate engineer could use than he had 20 or 30 years ago.

In addition to the demands for increased technical knowledge required of today's engineer, there are social, humanistic disciplines that must be included in the undergraduate curriculum to satisfy the demand for a broad education. The equally imperative humanities provide a background that helps the engineers to generate a frame of reference from which to view his activities. More and more engineers are also being sought for management positions, as pointed out by Friedlander[3] and Spaght.[4]

In short, there is a demand to expand the depth and breadth of the electrical engineering curriculum in many ways; and, at the same time, there is a tendency to reduce the number of classroom hours to meet the competitive pressures of the schools of arts and sciences at the universities. The resulting electrical engineering curriculum is therefore a reconciliation of the many demands on the various elements of engineering faculties to include the material that seems to be most important for the future growth of engineering, the relative interests of industrial firms, the current interest of students, and the advances in technology.

Quality of the program

It is believed that the effect of the pressures caused by the explosion of scientific advances and technological and social changes have improved education of the undergraduate and graduate students in electrical engineering. The graduates currently leaving universities are more qualified than their predecessors of five or ten years ago.[4] However, it is distressing that some utility executives who are responsible for making many of the technological changes possible are not quite happy with today's graduates. A typical expression of discontent is given in the introduction to a collection of Cornell College engineering lectures by Sporn[5]:

"My feeling of dismay has been heightened during these years by the gradual but cumulative changes in the curricula of our colleges of engineering that have shifted the emphasis from engineering to science-mathematics, physics, chemistry, and, conversely, have led to the neglect of some of the long established, if inarticulated, basics of engineering .... The blame for this, if as I believe blame exists, lies with engineers and especially with the school of engineering . . . "

There is very little likelihood, as explained in the preceding sections, that some of these dissatisfactions can be resolved. They certainly cannot be unraveled by returning to the curriculum used 20 or 30 years ago, when electrical engineering departments catered largely to the power industry, and the present diversity of opportunities was not available to the graduate.

Because of the much greater scientific and technical knowledge needed by current engineering graduates, the universities have consciously elected to teach topics that they believe to be fundamental, and that a student would have the greatest difficulty obtaining after graduation. Universities, very much like industrial establishments (as explained so well by Suits[6] in his talk on "Selectivity and Research"), have to concentrate their effort. Thus, many important aspects of engineering, such as competitive pricing of material and detailed design techniques, have been abandoned at the colleges and turned over to industrial training, where, because of the diversity of needs, it is being done more effectively. On the other hand, the topics that remain in the colleges usually include a great deal of mathematics and science, with an application orientation. It is the experience of educators that most of the mathematics the average engineer is going to use is acquired at college. Only a very limited number of graduates show the interest, ability, and drive to develop new mathematical tools on their own initiative. Seldom will the utilities allow a man on the job the time to learn the new techniques in mathematics necessary to follow advances in engineering analysis or system design. The general attitude is that high-toned theories are not practical, because they are not understood. This attitude generally lasts until the younger generation understands the methods well enough to prove them practical by solving important problems.

Personnel needs of the utilities

A recent study published by a committee of the American Society for Engineering Education[7] indicates that the investor-owned utilities employ yearly 1000 new engineers, only 600 of whom are electrical engineers. No figures are available for municipal, state-owned, and federal utilities. However, assume they appoint 150 young electrical engineers annually. Then the number of newly appointed electrical engineering personnel on the B.S. level is approximately 750. In addition, about 50 master's-degree-level electrical engineers and about ten young scientists with doctorates in electrical engineering will be needed for the electric utilities. With this rather limited number of students, it would be uneconomical for all 160 electrical engineering departments to provide facilities for the education of electric utilities engineers. Additionally, there are too few faculty to carry out the programs at all institutions and at all desired levels. It appears reasonable, therefore, that the educational programs for power-system engineers should be concentrated in perhaps 15 to 20 colleges or universities. This would permit building up a sufficiently comprehensive program to train students in the disciplines of particular interest to the utility companies. With such concentration, the utilities might capitalize on the current university situation more effectively than they have in the past.

The key questions are: At what level should such a specialized program be undertaken, and how should it be organized? The authors feel that it will take a three-part program to create the manpower that utilities need. First, some students must be recruited at the undergraduate level, preferably in their junior year. Second, expanded opportunities for graduate work and research must be made available. Third, a program of continuing education should be initiated to update engineers who have lost touch with the rapid advance of scientific knowledge and new engineering techniques.

Opportunities at the undergraduate level

The end of the junior year appears to be the most opportune time to interest undergraduates in the power industry. This may be accomplished by employing the student either in industry or in helping with research activity in the power field at the university. However, it is most important that the power industry provide challenging and rewarding jobs to the undergraduate senior. It does the power industry irrevocable damage to employ a student at menial tasks. (This, regrettably, was the experience of one of our straight-"A" students last year. Not only he, but many of the best of his classmates, are lost to the power industries forever.)

Both authors have had a most rewarding experience concerning excellent undergraduates on university research projects, under the sponsorship of the National Science Foundation and the program of undergraduate research in engineering. Nine students, all of whom had averages of "B" or better, had been selected for this ten-week scholarship plan during the summer of 1965. Three of the students selected topics in the general field of power. The close liaison of the professors with the students during the entire summer awakened the interest of the students in the power field. Now these students have graduated. One is engaged in graduate work in power-system engineering; a second has joined the Navy and is being trained for the design of nuclear power plants; and the third is with a manufacturing company. All three have responded to the challenge of realistic problems with great enthusiasm. They have discovered what self-education and the search for knowledge actually means. In order to make a final evaluation of such programs, additional activities must be generated at both the universities and the utilities.

Students live in a competitive world; and they experience pride at being professionally pursued during the job interviews in their senior year. The utilities must compete for the good student by offering attractive opportunities with both competitive salaries and the potential for either technical or managerial growth. Considering the poor image the power industry currently presents to students, this still may not be adequate to attract the manpower needed in the immediate future.

The institution of summer programs between the junior and senior years, and possibly a conditional scholarship program, could lead to a competitive advantage for the utilities over other parts of the industry. The conditional scholarship could require that, during his senior year, a student elect specialized courses in the power field. A high percentage of the students taking these courses could be expected to enter the power industry.

Graduate education and research subsidies

The privately owned, tax-paying electric utilities spent about four billion dollars in 1965 in investments, mainly on new plants and other facilities. The new equipment and systems are more complicated than the old; and, for economical operation, they require better-educated engineers. It is likely that developments in other than generating techniques could be applied profitably to advance public utilities. Disciplines such as the mathematics of optimal control systems and the physics of the development of large controlled rectifiers require training beyond the B.S. degree. Additionally, advanced training is going to be needed to evaluate such developments as nuclear power stations and high-voltage dc transmission. The utilities should expect that 10 to 20 percent of their new engineers will require advanced training in either business or engineering, training that can be expected to include advanced mathematics, possibly some advanced physics, and work in a professional area such as system optimization or the design of high-power components.

The need for advanced training has been recognized by other large manufacturing organizations. Because of the concentration of these large organizations, engineers in some localities have been able to organize educational centers in cooperation with a neighboring university. Occasionally, the course is given in their plants. However, the electric utilities are at a disadvantage in connection with this type of training, since their engineers are often widely dispersed. This means, for the most part, that they would have to send their people out of town to get advanced training, and also would have to provide a level of support that, up to now, has not been available.

For the masters'-degree programs, cooperative schemes in extension work may be feasible. However, for those gifted students who should be encouraged to work on a doctorate of engineering or philosophy, this type of program will not be satisfactory. Programs of independent study and research imply not just a series of courses, but a way of life that can be acquired only as a result of being immersed in an appropriate atmosphere.

Fellowship programs for doctoral candidates should be expected to run for several years, and a level of support should be provided so that financial problems are not a major worry for the student. Another reason why the utilities should support doctoral programs is to avoid the situation that exists today in connection with the high-voltage dc transmission problem. At present, a considerable amount of experience for the design of these systems has to be imported from a small country abroad, simply because research in this field has only recently been started here.

The universities are among the best places for so-called pure or self-initiated research, research that apparently is not headed for any "practical" application. History has shown that much "nonpractical" research remains so only temporarily. Faraday, Ampère, and Oersted never dreamed that the results of their experiments would end up in 1000-MW turbogenerators, or in trains traveling at more than 300 km per hour. The universities have been successful in their research, and many new product developments have been based on the results. A few of the more dramatic ones are nuclear energy, automatic controls, electronic computers—and all are great aids to industry.

The lack of utility-oriented research at universities does not result from a dearth of appropriate problems available to professors and students. The absence of research is caused by the lack of funds and sufficient communication. The utilities have major problems in the analysis and optimization of large-scale interconnected systems and power pool operation, in the area of power system stability and optimization and high-voltage dc transmission, and in the development of direct-energy-conversion devices for the generation of large blocks of electric power. The universities, however, are probably not the most appropriate places in which to study all these problems and their direct application for individual electric utility organization. However, the accumulated creative talents at universities could be best suited to study some of the long-range problems that involve the development of new techniques of analysis, or new methods and devices for the solution of future problems. The time scale of research activities in universities is such that they cannot help meet the day-to-day operating problems of utilities. The time scale and the team of talent at the university make it most suitable to attack and solve problems that could lead to large profits for industry in periods of from two to 20 years.

Such problems might include fundamental studies of the properties of dielectrics, with a view to synthesizing better insulating materials, or fundamental studies, such as the conduction process of metals and liquids, that could lead to novel transmission-line concepts. For example, it seems that it would have been advantageous for the utilities, as a group, to have participated in the research leading to the invention of the silicon controlled rectifier, as well as its development into a high-power device to be used with dc-to-ac conversion equipment.

If the power industry were to concede that long-range research investments of the type just discussed are worth the price, as have other parts of the electronics and chemical industries, it would derive large secondary benefits in the training and development of both new graduate students and young faculty members with an interest in problems of concern to the utilities. As an example of how this program may work, consider the need to develop a special-purpose computer language in which it is easy to write power systems analysis problems. The graduates of such a program would be at the forefront of the knowledge and techniques in this area, and thus could become useful members of utility engineering departments even if the results of the specialized research did not contribute all the answers to the immediate problems.

The graduate program is needed also to prepare young professors for teaching in subjects related to the power industry. Within the last decade, the Ph.D. degree has become a prerequisite for a successful career in the academic world. Although this requirement may be pure nonsense and should be waived in many cases, it is a fact of life that can hardly be changed. Thus, if the present situation continues, it will be a matter of only a few years before the number of professors with adequate training and interest in the power field will be alarmingly reduced.

Continuing education of engineers

Certainly the explosion of scientific knowledge has many ramifications, not the least of which is knowledge obsolescence. Today, the expected "half life" of an engineering education is estimated at something less than eight years.

Pressures exerted on engineering curricula to keep pace with expanding technology have produced an ever-increasing technological gap between today's graduate and the graduate of a decade or more ago. Changes in technical nomenclature and the introduction of better mathematical tools alone have created a communications problem between today's graduate and his earlier counterpart. In recognition of this existing gap, it is imperative that industry and universities accelerate their efforts to provide meaningful educational programs that will bring the professional engineer up to date with today's technology.

Some recent bright spots on the horizon are evidenced in the increasing number of short summer institutes sponsored by universities, and in the increasing number of formal courses offered by industry, such as Westinghouse Electric Corporation's "New Engineering Concepts" and "Modern Engineering for Westinghouse Management" programs, or the Bell Telephone Company's "Regional Communications Engineering School" program. A word about the last program is in order, because we have had a Communications Engineering School at the University of Colorado since the program's inception in 1960. The prime objective of the program is to update the technical education, and provide the foundation for continued self-education, of the Bell System engineers who are not less than three years or more than 15 years away from their last formal university courses.

About 50 engineers of the operating companies in the Bell System are brought to the campus for 22 weeks, in three- and four-week sessions. Concentrated formal course work is offered on such topics as modern circuit analysis and electronics, switching logic, switching systems, economics, probability theory, computer logic, and computer programming. The curriculum is the result of a joint effort of Bell engineers and University of Colorado faculty members, and is continuously reviewed, updated, and revised to reflect the current state of the art. Largely because of the farsighted attitudes and the excellent spirit of cooperation of the Bell Telephone Company, the presentation of new topics and the introduction of new teaching techniques have been included in the program. This has led to revamping of, and the introduction of new topics to, existing university courses. There has been an enthusiastic expression of satisfaction from both the faculty and the company, with benefits to each as a result of this program. We cite this as an example of what can be done, once the decision to act has been made. That such programs represent a considerable financial investment is apparent, but Benjamin Franklin reminds us that "an investment in knowledge pays the best dividends." To put such programs into effect, one needs a strong faculty with interests in a power program, financial support, the cooperation of other engineering departments and of public utilities, reasonably convenient physical facilities, and, above all, a group of good students.

Faculty requirements

No one disputes the fact that faculty excellence is of primary importance to the success of any university program. In order to graduate 750 students a year on the B.S. level, 50 on the M.S. level, and 10 on the Ph.D. level, about 75 professors would be required for the power field. Assuming that 25 professors were available now, 50 new professors would have to be appointed. Many others would be needed to provide support in other branches of electrical engineering, mathematics, and physics; but it is assumed that they are available at the universities.

It is important to note that in order to form a nucleus in the specialized areas of interest to a power group, it is necessary to have a minimum of three to five professors with interests in the needs of the utilities. It would be very difficult to maintain the breadth of interest or the intellectual exchanges required to keep a program alive and current with fewer professors.

Different institutions could be expected to specialize in different fields. For example, one school's program might concentrate on problems of circuit breakers, including the problems of vacuum surfaces and plasma lifetimes. Another school might be involved in the transient performance of large synchronous machines and a third in the characteristics of nuclear power plants. In this way the sum of the groups on various campuses could provide the utility industry with technically trained talent as well as with research data for a broad segment of the industry. These organizations could also provide the personnel for the continuing education programs. It should be obvious, at this point, that what is needed is an organized effort, planned on a scale large enough to make significant impact on the needs of the utility industries.

Cost of the program

The stipend for the recommended total of 750 seniors during the ten summer weeks following the junior year, and during the last undergraduate year, would amount to $1500 for each student. The universities should, in addition, according to the practice of foundations, receive an overhead allowance of approximately $750 per student, so that the cost for support of the undergraduates would amount to $1 837 500.

The previously noted requirement for 50 M.S. students and ten Ph.D. candidates would represent an approximate enrollment of 80 graduate students during the academic year. The support for each of these students would amount to about $3600 a year; with approximately the same rate of overhead as used above, this would require $5400 a year for each student or a total of $432 000.

The total of 50 new faculty members (on the basis of 750 B.S., 50 M.S., and 10 Ph.D. degrees each year) with salary and overhead, including pension, health insurance fees, secretarial support, etc., can be estimated at about $1 200 000. An additional $500 000 yearly, excluding salaries, should be allocated for research expenditures, cost of models, computers, traveling, etc. Four million dollars is an impressive sum!

Where to 'find' four million dollars

The hidden crises in the education of electrical engineers involves people, facilities, and money. The greatest of these, many believe, is money.

More money would attract the better students to the power field.

More money would strengthen college faculties and make it possible to appoint more faculty members in the urgently needed power area.

More money would permit the establishment of new scholarships, fellowships, and loans to students.

More money is the great need, but where should it come from? A very satisfactory experience is reported in the introduction, by Gardner, to Spaght[4]:

"Of all the interlocking revolutions of our time, none is more crucial for the future of the nation than the revolution in the role of trained manpower. Alfred North Whitehead said, 'In the conditions of modern life the rule is absolute, the race which does not value trained intelligence is doomed!'

"A number of our more farsighted business leaders have understood quite clearly the implications of that truth. In the 1950s, at a time when our colleges and universities were in grave need of financial assistance, a number of leading business corporations stepped forward with a vigorous campaign to provide such assistance. The effort stands as one of the landmarks of responsible business leadership."

D. C. McGraw, president of McGraw-Hill, Inc., a strong defender of the free enterprise system, recorded the same sentiments in a message headlined "Corporate support for our colleges." He noted that, whereas the total amount of dollars contributed by United States' corporations to education has continued to rise slowly, the rate of the annual increase has decreased. He believes that corporate contributions to higher education are important for the good health of the business community. Is it unreasonable to suggest that the public utility industry provide the funds for the specialization of their future engineers?

At present, the billings of privately owned, taxpaying electric utilities represent a yearly rate of $15 to $16 billion. The billing of the utilities belonging to the American Public Power Association (APPA) is of the order of $3 to $4 billion dollars per year. If two cents out of every $100 of billings were deposited in a special educational fund, the necessary money would become available. This, the authors know, would be a self-inflicted assessment on the already highly taxed industry. However high the total price seems, it still would be a fraction of the rate of contribution by other energy industries.

M. E. Spaght[4] describes the contribution of American Shell as follows:

"You might be interested to know that our total program of aid to education, all projects I have discussed, will cost, in 1964, one and one-half million dollars."

If the utility industry were to support education at the same rate as Shell, its contribution to education would be at a rate of $9 million per year.

The Esso Corporation, through its Esso Education Foundation, expects to contribute $2.35 million for 1965–1966, and $2.5 million for 1966–1967.

Rittenhouse[8] has expressed the realistic views of colleges as follows:

"This practice of tailoring the staff to work-load requirement is certainly not an undesirable one. It is precisely the practice of industry; so, until industrial complaints regarding the products of engineering curricula are matched by adequately financed programs to modify curricula and staff-content trends, the educators are perfectly right in pursuing the courses which they have chartered for themselves. What else can be expected in the absence of adequate guidance from industry-oriented minds and subsidies . . .?"

A new task

The suggestion is often made that each electric utility company should single out and support a university by providing funds for special professorships. This, the authors believe, is not workable, however attractive it may seem. (E. Greenfield[9] has quoted some of the conservative opinions of utility executives.) One cannot expect college administrators to fall on their knees and ask for handouts. The funds should come with the understanding that a service provided for the industry is being paid for.

It is suggested that the task of the Electric Research Council should be extended to become the Electric Research Council and Power System Education Foundation. The investor-owned electric utilities should establish an educational foundation as a branch of the Edison Electric Institute (EEI), and the APPA should do the same. The EEI and the APPA could then collect contributions from their member companies at the rate of a suggested two cents per $100 billings. The Educational Foundation at the Electrical Research Council, together with the EEI and the APPA, should select a suitable number of universities or colleges and interest them in programs such as those described in this article. The funds to the universities would be distributed by the Educational Foundation. There is ample precedence for such support of universities by private foundations.

In order, however, to receive the cooperation of the utilities, it is suggested that the specialized senior-year student programs and the graduate research programs be established regionally, by joint planning between the selected universities and neighboring utility companies.

The Edison Electric Institute and the American Public Power Association have, for many years, seen the necessity for member relationships between the utilities and colleges. Nearly every year, institutes and conferences are organized on engineering education to investigate methods of escaping from the blind alley in which the utility recruiters find themselves. The investor-owned electric utilities and the members of APPA are in a position to have an organized Electric Research Council that can carry out the task of re-establishing leading influence for the utilities at some of the universities, and thus obtain the necessary young, advanced manpower reserve for the fast growth of industry.

Conclusion

In the cold light of figures, which could be amplified and detailed, it is quite clear that the privately owned electric utilities can obtain the highly qualified manpower they need if they are willing to subsidize the necessary programs.

Words and fine thoughts will not be enough to translate this or any similar program into action. It will require work and diplomacy of a high level to raise the funds and to convince universities that the program is worth undertaking.

As the situation now stands, the public utility simply is not competitive with other segments of the industry, such as electronics, aircraft, and the telephone system. To get their fair share of the manpower and faculty interest, the utilities must do more than they are doing. The present situation need not persist, and we would welcome the opportunity to help change it.

Although the authors feel that many of their colleagues in the educational world may share the views presented here, the views are not necessarily those of the faculty of the College of Engineering at the University of Colorado, and are the sole responsibility of the authors.

Prof. G. J. Maler contributed the section on "Obsolescence and continuing education." The structure of the paragraph concerning "more money" follows closely an article in *The Johns Hopkins Magazine*.[10]

REFERENCES

1. McEachron, K. B., Jr., "What power companies can do to assist in engineering education," *Proc. Edison Elec. Inst. Conf. Eng. Education*, New York, N.Y., 1964.

2. Kidder, A. H., "Power engineering needs in education and professional development," *IEEE Trans. Power Apparatus and Systems*, vol. PAS-84, pp. 334–338, Apr. 1965.

3. Friedlander, G. D., "Rise of the engineer–executive," *IEEE Spectrum*, vol. 2, pp. 113–116, Sept. 1965.

4. Spaght, M. E., *The Bright Key*. New York: Appleton, 1965.

5. Sporn, P., *Foundation of Engineering*. New York: Macmillan, 1964, pp. 2–3.

6. Suits, C. G., "Selectivity—a modern research necessity," presented before the American Management Association, Chicago, Ill., Sept. 15, 1964, GE Research Laboratory Rept. GP-0300A.

7. Smith, W. P., *et al.*, "Report of the Committee on the Educational Needs of the Electric Utility Industry," Elec. Eng. Div., ASEE, June 1965.

8. Rittenhouse, J. W., "Engineering education at crossroads," *IEEE Trans. Power Apparatus and Systems*, vol. PAS-83, pp. 817–926, Aug. 1964.

9. Greenfield, E., "Manpower needs in electric power engineering," presented at American Power Conference, Chicago, Ill., Apr. 28, 1965.

10. Committee Report, "The plight of the humanities," *Johns Hopkins Mag.*, vol. 16, pp. 28–29, May 1965.

Feedback from the field

Bradley Cozzens
Assistant to the General Manager,
Department of Water and Power, Los Angeles, Calif.

Professors Erdelyi and Barnes are indeed to be complimented for bringing to the front the problem of engineering education, not only in the field of power engineering, but in electrical engineering in general.

Although the authors list, in their opening paragraphs, three of the major problems, one appears fundamental. With almost four times the percentage of high school graduates entering college in 1965 as in 1924, the past decade has shown a relatively insignificant increase in the number of college graduates entering the engineering profession. The authors list four major items as contributing to this lack of interest in the engineering field; I believe, however, that the major responsibility falls upon the high school counselors and high school teachers. All too frequently, a high school graduate of good engineering potential finds that he either has not taken the appropriate subjects or has received such poor grades in mathematics and science that he does not meet college entrance requirements. A few students will spend the extra time to make up these deficiencies, but the majority will enter some other field.

In many cases, high school teachers themselves either have little knowledge of the applications of mathematics and science to the engineering profession, or they are purely indifferent with respect to the pupils' interests in these fields. It is in this area that I believe great added effort is needed. It was to this end that the Engineers' Week Committee of Los Angeles last year awarded approximately 80 certificates, upon recommendation of high school principals, to those teachers in the mathematics and science fields who had contributed the most in promoting student interest and study habits to equip students for college entrance in engineering. There is little reason why twice as many students should not be entering the engineering field, since knowledge gained from this type of study has application in many areas, with appropriate remuneration.

The engineering curriculum

I believe that the authors and I are in general concurrence with respect to curriculum. Although there is no doubt that today's engineer with either a four- or five-year degree has a much greater knowledge than the graduate of 20 years ago, with the vast amount of new material developed during these two decades it is doubtful that any four-year course can equip him with the same proportion of applicable knowledge that the engineer of 20 years ago had to acquire.

This all points to the need for five years of training in advance of full engineering employment. With many, the financial strain would preclude such extended study; therefore, the use of advanced study in local institutions, either at night or under part-time arrangements, as covered by the authors, is a necessity, and presents a very acceptable solution.

Special studies for direct application to the power field must be developed by somewhat formal class work in the larger utility systems, but can be performed much more economically under advanced studies if local universities are available close to the utility system. It is the loss of professors with power engineering knowledge, either by attrition or the lack of new persons entering the field, that I believe is the most serious problem in connection with our engineering training today. Without such trained professional talent, advanced or special studies in the power field cannot be programmed at the university level. As the authors have stated, the majority of the universities are in no position to teach advanced or special classes of direct application to power utility problems.

Employing students at utilities

The suggestion of using students in summer research projects who have completed the third year of college, would, I believe, produce little for either the utility or for the engineer. First, the time available is not sufficient to develop any definitive results with respect to most problems; and, second, the student at this level frequently is not in a position to contribute materially to research. The employment of such students on a temporary basis in utilities, with moderate remuneration, probably will produce the greatest stimulation of interest and acquaintance with utility problems at the least cost to the utility and the greatest benefit to the student. The employment of professors during such periods likewise will assist in orienting them to the current advances in the utility art, and their background should contribute materially to the solution of utility problems.

Although I doubt that a greater interest on the part of utilities in engineering education and universities would have created the group of engineers and scientists to develop the necessary hardware for high-voltage, dc transmission in the United States, rather than in Sweden, I must concur in the authors' thinking that the utilities' management has been subject to the cyclic trend of growth, particularly in the field of high-voltage, large-unit requirements.

A large high-voltage laboratory on the West Coast was disbanded in the late '40s because most of the utilities felt that the state of the high-voltage art was sufficient to meet their future needs. Since the early '60s, however, with a continuing growth and requirements for higher voltage, studies in the United States and Europe have taken on a relatively crash-type program of research in order to develop 500-kV and 750-kV equipment.

With greater foresight, these high-voltage systems could have been developed during the decade of the 1950s, thus retaining most of the university high-voltage laboratories for continuing use.

The authors mentioned that universities in general are not in a position to take on the research necessary to solve day-to-day operating problems. Mention is made of the properties of, and need for, synthetic dielectrics. The major problem of developing a high-voltage underground cable, with low dielectric loss and reduced charging current, has been allocated by the Electric Research Council to a contract with a manufacturing agency rather than a university. Again, this is primarily because of the time requirement for the solution of this problem.

Most of the problems facing the utility today require answers on such a time schedule that it is doubtful that the universities, without a special full-time research program in these specific fields, could fit the activities into their schedules in time to meet the utility's requirements. Some of the universities do have technical institutes where such research is a continuing activity throughout the year, and the augmenting of universities in this manner might be a partial solution to the problem.

I must disagree with the authors, however, in their statement that a few schools should be selected for the teaching of power. Similarly, I would disagree that other items, such as a special computer language, might be developed for the power field. Those who are continually using computer programs and exchanging them with various other industries, indicate that the use of a more universal language, such as Fortran or Computer Language I, applicable to everything from stress analysis of steam piping to nuclear power generation problems, is much more valuable than attempting to develop a separate language for the power field.

Although this is a day of specialization, I believe that, with the vast amount of new knowledge continually becoming available, it would be particularly unfair to the engineering student to direct his training in the first four years of college extensively into the power field. Such training should be more general, looking toward the absorption of as much knowledge and source data as can be acquired. Specialization probably should be moved into the fifth year, or into graduate work.

This lends itself to the continuation of research as part of the graduate program, and as part of the "continuing education of engineers," including refresher or updating courses as referred to by the authors. Utilities very definitely could and should become interested in such programs. They could participate with both personnel and financial assistance.

A question of money

Regarding the suggested methods of securing funds, I cannot concur with an assessment from utility income. Electric utilities are based on a relatively long life, with facilities ranging from 20 to 40, or even 50, years. Thus, the annual income is a relatively small portion of the capital investment. For example, the most recent statistics published by *Electrical World* in their issue of February 20, indicate that privately owned utilities carried an investment of $75.9 billion; the income from electric revenue was listed as $13.77 billion. Most industries outside of the utilities will show an annual income approaching, or even amounting to several times, the capital investment in the facility.

Furthermore, private agencies paid over $3 billion in taxes, whereas public agencies contributed to local taxes, or to city funds, amounts probably equal to, or even in excess of, this proportion of their income. The economic stature of a nation, and of a community, is largely related to the cost of energy supplied, and it is for this reason that I am definitely opposed to any further burdening of the costs associated with supply of electric energy.

The Federal Government, in allocating utility as well as other tax funds, is spending well over $3 billion in research, of which, for the year 1965, over $1.66 billion was allocated to studies in colleges and special research centers. Since these allocations were largely associated with space or military programs, the Federal Government is in direct competition with the utilities for engineers, using tax dollars and the available staff personnel on these research projects.

Current legislation is being considered to allocate some funds, basically related to health and beautification, to electric power and transmission research projects. If the need, as indicated by the authors, is of the order of $2 million—and particularly if this is limited to the graduate study and research program—it would seem appropriate that a portion of the $1.66 billion of federal funds should be diverted to provide for this need.

The utilities must participate, however, on a local basis, in directing or guiding research programs in their specific areas, and in fostering the continuing education or retraining of their personnel. This can be done by assisting the colleges in providing advanced study, either with or without credit for advanced degrees, to expand the knowledge of younger technical personnel in their organizations who, because of the current generalized curricula need specialized knowledge of high-voltage phenomena, system characteristics, and nuclear power theory, as well as the application of solid-state physics knowledge to utility systems.

With but slight modification, I believe that we can concur in the general desires of Erdelyi and Barnes to immediately institute advanced training, in the field of power engineering, at college levels, so that we may at least develop the necessary faculty to satisfy our educational needs.

Larry Dwon
Manager, Engineering Manpower,
American Electric Power Service Corporation,
New York, N.Y.

I. Partial list of schools with stipulated programs in power system engineering

Schools	Type of Program
1. University of Akron	Master's degree program
2. Clarkson College of Technology	Professorship for undergraduate program and future master's degree program supported by Niagara Mohawk Power Company
3. University of Florida	B.S., M.S., and Ph.D. programs and research supported by Florida investor-owned electric utilities
4. Illinois Institute of Technology	Professorship for graduate program in power systems, supported by five companies
5. Iowa State University	Undergraduate courses in power and graduate programs in utilities engineering and electric power, including research supported by affiliates
6. University of Maine	Postgraduate program, with local utility support
7. Newark College of Engineering	Master's degree program
8. Northeastern University	Five-year B.S., six-year M.S. program, supported by 23 utilities and two manufacturers
9. Ohio State University	Ten graduate fellowships, supported by seven Ohio utilities
10. University of Oklahoma	Professorship supported by Oklahoma Gas and Electric Company
11. Purdue University	Purdue Energy Research and Education Center, with graduate program in power, and support by electric utilities
12. Rensselaer Polytechnic Institute	Professorship and fellowships, supported by electric utilities and other companies
13. Texas A&M University	Research and graduate program supported by Texas electric utilities
14. Tulane University	Electric power laboratory, with local electric utility encouragement
15. Virginia Polytechnic Institute	Electric energy research program for master and doctoral candidates, supported by Appalachian Power, Kentucky Power, Potomac Edison, Electric Power, and Vepco
16. University of Wisconsin	Professorship in power, including research and graduate program, supported by Wisconsin Electric Utilities

The article by Erdelyi and Barnes primarily suggests a method of supporting campus research in electric power systems engineering. This thesis appears to be the same as one described in their article, "Invest in the Future of Young Electric Utility Engineers."[1]

Essentially the same idea was discussed at the 1965 IEEE Summer Power Meeting in Detroit, Mich. At that time, Professor Erdelyi gave the impression that the best way, and perhaps the only way, to achieve an adequate supply of properly educated engineers for electric utilities was for the power companies to support research on engineering campuses. In discussing this thesis, this writer contended that, although research is an important criterion in the solution of this problem, there are many other methods that the power industry should also use to change the situation. These several areas have been described in papers by this writer to which, unfortunately, the authors have not made reference.[2,3] It is the specific approach to research on the campus proposed by the authors with which I disagree.

However, before discussing that point and several other statements in the paper, let us first establish the areas in which substantial agreement exists. I agree with the following:

1. Specialized training for engineers who wish to work in the power field is currently available at very few schools. (However, the number of schools showing interest is increasing at a surprisingly satisfactory rate compared with the attitude that existed at the beginning of this decade; see Table I.)

2. The number of younger professors teaching power courses is relatively small; and, if the supply is not replenished, it could seriously affect the future. (However, there are now significant signs of growing interest among younger men to teach power. They need encouragement.)

3. High school students know very little about engineering as a vocation. (However, as chairman of the ECPD Guidance Committee, I can assure the readers that much effort to disseminate information and to improve engineering guidance methods has been instituted. The NSPE, ASEE, JETS, technical societies, and many other groups are combining their efforts toward a unified approach.)

4. Engineering programs are difficult, and are not as popular among students as are other subjects they might study. (However, other professions have similar problems, because, as the authors write, there are other ways to make a living that require a less continuous drive and urge to learn the difficult subjects.)

5. There is a continuing demand to increase the depth

and breadth of electrical engineering curricula, which has the tendency to reduce engineering content. The eliminated courses are those that do not appear to some educators to be as important as mathematics, science, and the engineering sciences. (However, the "Goals of Engineering Education Study" seems to reveal a growing dissatisfaction with the expansion of conceptual courses of study at the expense of the more pragmatic disciplines.)

6. Educational programs for power systems engineers should be concentrated in a few schools (15 to 20). (This base seems to be evolving already; see Table I.)

7. The three-part program described by the authors (say, two good undergraduate courses to inspire the better students toward power, graduate programs to teach advanced power courses in depth, and a variety of continuing education programs to keep practicing power engineers in tune with evolving engineering and scientific knowledge and methods) is a must to maintain. (Jack Young, of the Edison Electric Institute, reported on such programs and they appear to be very extensive.[4])

8. The end of the junior year is the most appropriate time for engineering students to be given challenging assignments (no other kind should be considered) so as to motivate them toward in-depth study of power systems engineering and careers in this important field. (However, cooperative programs, such as the one at Northeastern University, which have been especially developed for the power industry and which maintain a high order of challenge at school and in industry assignments, are even better ways to attract good students, and to motivate them earlier toward the power field.[5, 6])

9. It is a must for students and professors to be exposed to interesting, educational, and challenging assignments in industry if they are to be influenced toward the power field. I agree that it is regrettable and, for that matter, foolish, to misutilize good students as described by the authors. (However, it is equally regrettable that those professors who do recommend their students to such summer experiences are not more selective among power companies. Such results as described would not occur at the American Electric Power Service Corporation nor at other enlightened companies.)

10. A graduate program is needed to prepare professors to teach subjects related to the power industry. (However, such programs should be carefully planned with the industry's help. It should insure that the men interested in teaching also get extensive experience in the industry, preferably before they enter their Ph.D. program of study, or at least before they start their thesis. American Electric Power has been helping in this kind of approach for several years.)

There are other minor points of agreement; but let us turn now to the debate.

Educational needs of the industry

It is well, first, to preface the points of disagreement with the statement that power engineering education is needed not only by engineers for electric utilities, but for the whole of the greater power industry, including energy producers, power apparatus manufacturers, large users of electric energy, consulting firms, and numerous small companies using electric energy. It is not proper to single out the electric utilities as the only industry in which power engineers are needed, yet educators generally, in the past (and some even today), seem to unburden their feelings on electric utilities alone. Their reference to numbers of engineers needed for power almost always seem to include only the energy producers. However, the demand for power engineers is much greater than any survey of the electric utilities alone would reveal.

I question the reliability of the ASEE committee's survey mentioned in the article. This survey has been challenged by several members of the IEEE Power Engineering Education Committee. I personally believe it to be a poorly conducted, and very biased, survey. I know it was not conducted on a random basis. I also have reason to believe that the companies surveyed are mostly small ones, the type that are not known for their progressiveness, innovations, or outstanding technical achievements. To quote figures from such a survey is harmful to the power image and the cause of power engineering education. The survey also gives an unreliable indication of the needs.

I am further disturbed to hear educators talk so often about the public utility industry as though it were a homogeneous mass, devoid of such progressive companies as AEP and others. These companies do not fit such statements as:

1. "Talented graduates available to utilities are already in short supply . . ." (This year, for the first time in four years, AEP did not obtain its quota of electrical engineers; however, it could have if it had been less selective. Necertheless, of 19 electrical engineers needed, we were fortunate to hire one Ph.D., seven M.S., and five B.S. degree graduates.)

2. "Seldom will utilities allow a man on the job the time to learn the new techniques in mathematics . . ." (AEP has an educational assistance program, as do other companies, for all employees. The students take all kinds of courses, including advanced mathematics and subjects in modern engineering concepts. For instance, two engineers completed their evening school master's degree program this year in operations research; others received masters' degrees in a variety of other areas. AEP sends people to masters' programs in nuclear engineering. One engineer is at M.I.T. studying for his Ph.D. degree.)

3. ". . . [the utilities] would have to send their people out of town to get advanced training, and also would have to provide a level of support that has, up to now, not been available." (AEP has provided a good amount of educational support, and has been experimenting with various approaches to improve the power image, and to attract engineers to this important career field.)

4. "A suggestion is often made that each electric utility company should single out and support a university by producing funds for special professorships. This, the authors believe, is not workable, however attractive it may seem." (If the authors believe this idea to be unworkable, then they must have closed their minds to truth. It has worked at I.I.T., and is working even better at R.P.I. As a matter of fact, other schools using such approaches include Clarkson, Drexel, and Oklahoma, with several others being discussed. The program does work, and it is one of several ways in which the problem under discussion is being resolved. This approach is no longer in the realm of theory; it is being practiced and it is being extended. How well it will work depends on many related factors.)

5. "In the cold light of figures, . . . it is quite clear that the privately owned electric utilities can obtain the

highly qualified manpower they need if they are willing to subsidize the necessary program." (Again, some utilities are doing quite a bit, and others are doing very little. In any event, the funding and other efforts should come from the greater power industry, not from just a portion of it, the electric utilities.)

6. ". . . the utilities must do more than they are doing." Granted, they should, but this statement might be more palatable if the word "some" were used. It also needs to recognize the fact expressed in statement 5 concerning the greater power industry.

The matter of money

Now let us briefly discuss the main issue—the professors' plan to fund campus research from a common Electric Research Council fund.

Proposals to increase the level of financing for research in power engineering and related areas need constant encouragement. The extent of this research, and the type of research that can be properly placed on engineering campuses, requires considerable thought and experienced judgment.

It is the philosophy of a centralized research program, carried out on behalf of the whole power industry, that contains basic weaknesses. Company objectives are different; people within companies, and their ideas, differ. What one company would judge to be a sound and vital research project another might disdain. It appears likely that a common research program might dissipate funds for mediocre pet projects rather than for the positive breakthroughs to needed knowledge and innovation.

Recently the Edison Electric Institute has had under discussion a Joint Research Council, through which investor-owned companies and government power agencies could jointly finance certain research projects that are deemed appropriate. This proposal has been the subject of intensive consideration and discussion by AEP engineers and top management personnel. The consensus resulting from the foregoing was: (1) it would be a mistake to increase expenditure for the EEI general research program; (2) it would be a mistake to increase the present level of financing for the EEI general research program; and (3) there is a need to try to get the industry to re-examine the research course upon which it has embarked. The same reaction would seem to pertain to the professors' "common fund" proposal.

On the AEP System, we have been, and continue to be, engaged in many vitally important (to us, and we believe to some of the industry as well) research projects. In several instances we were able to enlist the active cooperation of neighboring companies and of forward-looking manufacturing organizations. This regional approach to the solution of vital and significant problems can be accomplished in a more optimum manner, and thus conserve time, money, and manpower. Since it is a proved technique, we continue to believe it to be a good one.

The idea of a common, continuously replenishable bucket of research money, into which one might dip, by whatever means established, is not in keeping with sound private enterprise concepts. Some government agencies have used it and there has been much discussion as to its effectiveness. Some abuses and ill effects have been noted; and lack of control is only one consideration. AEP would not support the concept as stated.

REFERENCES

1. Erdelyi, E. A., and Barnes, F. S., "Invest in the future of young electric utility engineers," *IEEE Trans. Education*, vol. E-9, pp. 61–68, June 1966.

2. Dwon, L., "Forces influencing engineering education from Power," *IEEE Trans. Power Apparatus and Systems*, vol. PAS-83, pp. 826–837, Aug. 1964.

3. Dwon, L., "Here's an effective way to recruit and train power engineers—parts I & II," *Power Engineering*, pp. 49–52, Sept. 1964; pp. 53–55, Oct. 1964.

4. Young, H. J., "EEI survey of courses and conferences of interest to electric utility engineers," IEEE Conf. Paper 31CP67-191.

5. Dwon, L., "Power engineering cooperative education programs do enthuse students," IEEE Conf. Paper 31CP67-405.

6. Gaiennie, D. F., "Power systems engineering cooperative program at Northeastern University," IEEE Conf. Paper 31CP67-540.

W. A. Lewis

Department of Electrical Engineering,
Illinois Institute of Technology, Chicago, Ill.

The analysis of the problem of education for power systems engineers by Erdelyi and Barnes is thorough, comprehensive, and, I believe, highly accurate. My own assessment of the situation would be much the same. However, I do not agree completely with their proposals to meet the situation.

They have shown that engineering for power systems is important, complex, and challenging; but that the number of engineers needed is not great enough that all 160 engineering schools should attempt to provide the special training needed for the power systems area. In the long run, I think this premise must be accepted. However, the authors have offered no effective method by which those institutions to specialize in power are to be selected, and herein lies a tremendous difficulty when applied to undergraduate education. Electric utilities are famous for recruiting their engineering staffs from nearby educational institutions, particularly those within their service areas; and they have close bonds with these institutions through alumni relations, even if they are no longer successful in recruiting the number and kind of engineers they need from the graduating senior class. Some utilities have quite consciously been meeting their recruiting needs by hiring, on the rebound, engineers who initially seek employment outside the company service area and are later drawn back by family or regional ties, or by climate or recreational advantages. Thus the ties to nearby institutions remain strong, and ties to remote institutions are weak or nonexistent. When "the small number of institutions" is being selected, there is no possibility of agreement on any group of colleges that does not include the favored local institution. Therefore, I believe the idea must be accepted that the bachelor-degree graduate will still be recruited from the local institution, regardless of any other plan. This leads to the conclusion that bachelor-degree graduates will not have any degree of specialized training, unless all 160 institutions specialize adequately in power, an uneconomic and impractical alternative.

In the long run, I do not believe that this inevitable result is undesirable. Under today's conditions, the courses that formerly provided "specialization" in power, as viewed by most present-day faculties, have been replaced by courses that provide "fundamental training in modern technology," which means courses that prepare for work in electronics, communication, control, data processing, space navigation, and perhaps even acoustics, optics, or biomedical electronics. But the needs of power systems have grown in all these fields, except perhaps biomedical electronics, and even this may soon find application in the engineering of man into his environment. Therefore, any program that replaces any substantial part of the new material in order to specialize again in power may be shortsighted and detrimental.

Knowing the fundamentals

The authors find that today's engineer is "well trained." I believe this is true because he understands much of the new material that his boss knows about only vaguely. However, the danger is that he will not understand the fundamentals of power that the boss already knows, and that he must understand if he is to replace his boss in due time. Therefore, either the power companies must provide basic education in the business, far beyond what was needed years ago, or the specialized needs must be provided by further specialized education. I believe the answer lies in some of both. Those subjects that are common to all power systems, including polyphase circuits in balanced and unbalanced states (symmetrical components, for example), energy conversion processes, transients, surges, traveling waves, stability, principles of protection, economics of selection and operation, control systems, and process computers, as well as other subjects, can be handled more broadly and efficiently by a college specializing in these areas than they can be on the job. On the other hand, the application of these principles to the unique problems of an individual company, including design, reliability, preventive maintenance, and effective operation, can be learned effectively only on the job. For further education in the more academic portion, it only makes sense to attend an institution that specializes in these subjects, that is adequately staffed, and that is actually supported by the beneficiaries of the specialized service. Thus, the "small number of specialized institutions" is appropriate, and I believe workable, in the graduate area when it will not be in the undergraduate area. Institutions offering a high-grade graduate program can provide some "back-feed" to strengthen the undergraduate program in preparation for graduate work; but any attempt to provide strong specialization in the undergraduate area in a sense defeats the broad purpose.

Graduate training

Obviously, if students from many companies attend a small number of graduate schools, much more extensive cooperative programs, or fellowship programs, must be provided than have been available in the past. However, the facts of life are that a large fraction of the best students are now looking toward graduate training, and are not in the job market at the bachelor's level unless the job provides attractive opportunities for graduate study. So if the power industry is to recruit its share of the more able students, it must be prepared to offer opportunities for graduate training. In my opinion, the suggestion by the authors that 50 men a year should be trained at the master's degree level is far too small to be realistic and effective. The number should be three or four times as large, and most of them should be sponsored by their present or future employers. Until such a principle, or its equivalent, is established and accepted in today's market, the power industry will not even be able to talk to the kind of men it needs for its future. It is my belief that some engineers should be recruited for immediate graduate study; and others, recruited at the bachelor's level, should have the option of a year or more of graduate study, at company expense, after demonstrated good performance for a year or more. Such concepts may appear visionary to old-timers, but in my judgment they are utterly realistic under the needs of the present.

I have talked with several utilities about recruiting doctoral graduates, and have found them universally hesitant. "What will he do for us?" is the universal question. I think this concern is unwarranted. Every company has its tough problems, and is trying to find the solution with the best talent available. If a doctoral graduate is interested, and is recruited to work on the problems that exist today, he should be able, in a reasonable time, to provide a more penetrating analysis of the fundamental issues, and to suggest more perceptive attacks on these problems than a man without such broad and deep training. Part of his value should lie in his ability to identify the problems more clearly. After that, he can be depended upon to create his own job in solving them. In looking toward the possible use of doctoral graduates, they should not be treated as a breed apart, for whom special jobs should be established, but as ordinary engineers with greater potential for getting quickly to the heart of obscure problems. With the problems already on the horizon arising from the proliferation of nuclear generation, the pressure for underground transmission, the use of dc transmission with mercury or solid-state valves, the stability of regional interties, switching surges, possible new energy sources, air pollution, contamination, and many more, the immediate need is for a better understanding of what the critical factors in these problems really are rather than to dream up a new kind of problem for a Ph.D.

The power companies are beginning to feel crucial manpower shortages for the first time. The situation is not likely to improve materially until the problems raised by this article are adequately dealt with. The authors are to be congratulated for setting forth the problems so sharply.

Today's need for balanced urban transit systems

Contrary to popular opinion, it is a grave mistake for large cities to rely completely on freeways to solve all their traffic problems. Efficient transportation of people in metropolitan areas is best accomplished by a balanced system in which automobiles and buses supplement high-speed interurban and intraurban rail transit

Edward L. Michaels *University of Houston*

Cities must have freeway systems in order to facilitate the movement of traffic. After a city reaches a certain size, however, it soon becomes apparent that freeways alone cannot solve the transportation problem. The only solution to this problem is to provide a system of balanced transit. Thus every large city that has expanded very rapidly—Los Angeles, Houston, Atlanta, and many others—should be planning or building a balanced transit system, with railroad rapid transit (including suburban railroad service) as the core, augmented by freeways for buses and private automobiles.

Almost everyone is familiar with the various forms of transit used in cities to move large numbers of people. The automobile is the most familiar and desired form of transportation because of its comfort, convenience, and privacy. The bus provides the next most familiar form of city transportation. Some cities in the United States, including New York, Chicago, Boston, Philadelphia, and Cleveland, have rail rapid transit systems on separated rights of way such as the subway and elevated line.

Modern, high-speed rail rapid transit is the most efficient and economical method known for moving large numbers of people quickly and comfortably. It should, therefore, form the core of the transit system into which automobiles and buses can be used to funnel riders effectively from outlying sections. Properly designed, such a balanced transit system will relieve traffic congestion on freeways and thus make them more usable for those who must or prefer to drive their own cars. This relief of traffic congestion is just one of many ways in which a truly efficient balanced public transportation system benefits everyone—the user and nonuser alike. A reduction in automobile traffic will, in turn, result in a reduction in air pollution.

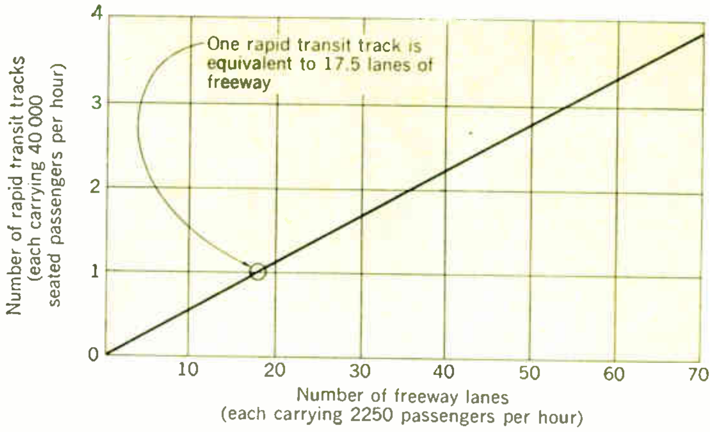
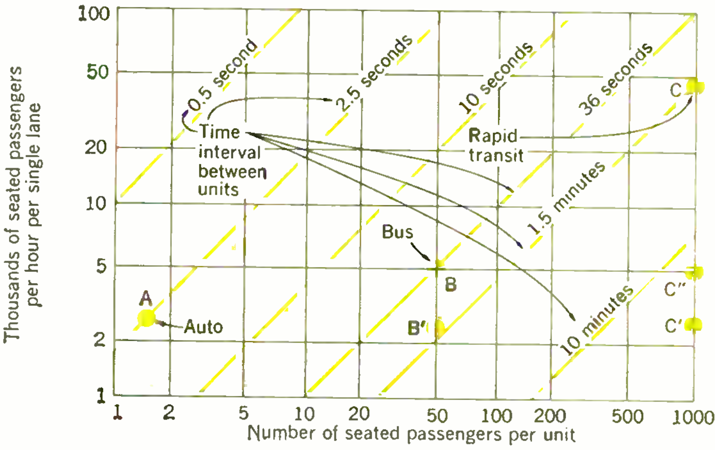


FIGURE 1. Graph showing the equivalent ratio of rapid transit tracks to freeway lanes.

FIGURE 2. Logarithmic scale plot of number of passengers that can be carried per hour on various modes of transit.



A comparison between the passenger-carrying capacity of rapid transit tracks and freeway lanes is illustrated graphically in Fig. 1. It shows that one rapid transit track can move as many *seated* passengers as 17.5 lanes of freeway traffic. This is based on the assumption that the average loading per automobile is 1.5 persons, and that the time interval between successive automobiles is 2.5 seconds on each lane. On this basis, each freeway lane is capable of moving 2250 people per hour. The figure of 40 000 seated passengers per hour per rapid transit track is based on the assumptions that each rapid transit car seats 100 persons, each train contains ten cars, and the time interval between successive trains is 1.5 minutes.

To compare the passenger-carrying capacities of buses with those of freeways and rapid transit lines, Fig. 2 plots on logarithmic scales the number of seated passengers per hour per single lane or track against the number of seated passengers per single unit (such as one automobile, one bus, or one rapid transit train) for various time intervals between successive units. Point *A* represents the maximum capacity of 2250 seated passengers per hour for one lane of freeway, and point *B* represents the maximum capacity of one lane of buses. The figure of 5000 seated passengers per hour per bus lane is based on 50 seated passengers per bus and a time interval of 36 seconds between successive buses. It is interesting to note that, if the time interval between buses is increased to 1 minute and 20 seconds, the passenger-carrying capacity of buses drops to 2250 per hour at point *B′*, the same as the maximum for automobiles at point *A*. The capacity of streetcars is approximately the same as that for buses because they are both of comparable size and operate in city traffic.

The passenger-carrying capacity of rail rapid transit is indicated by point *C* in Fig. 2. As already explained, a rail transit line, using a ten-car train that seats 1000 people every 1.5 minutes, will move 40 000 passengers per hour per track. Automatic computer control makes the operation of high-speed trains, spaced 90 seconds apart, entirely feasible, safe, and reliable. Point *C′* shows that one rapid transit track can move as many people per hour as one freeway lane of automobiles, if the spacing between trains is as much as 27 minutes. To move the maximum number that buses can transport (5000 per hour), one rapid transit train would be required every 12 minutes, as indicated by point *C′′*.

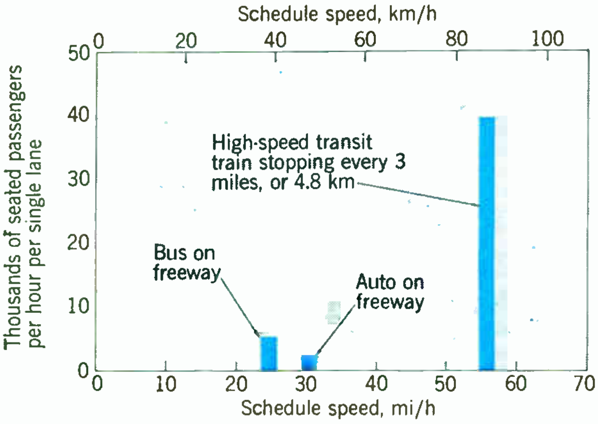
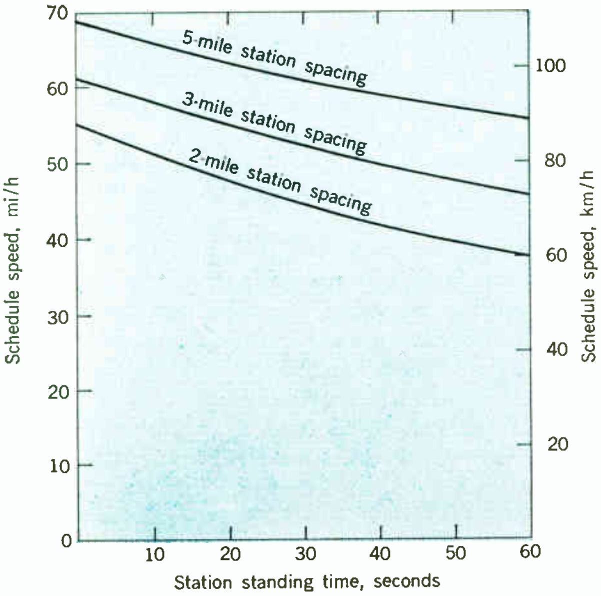


FIGURE 3. Graphic plot showing comparison of single-lane freeway passenger capacity with a high-speed transit train.

FIGURE 4. Effect of station standing time on schedule speed for three different station spacings assuming the use of high-speed equipment.



In Figs. 1 and 2, only the passenger-carrying capacity of various forms of transit is compared; nothing is said about speed. The speed of various forms of transit is compared in Fig. 3, which is a plot of passenger capacity versus schedule speed. Since freeway speed varies greatly with traffic conditions, the speed of 24 mi/h (38.4 km/h) is chosen on the basis of rush-hour traffic. It is less than the 30-mi/h speed chosen for the private automobile in rush-hour traffic because of time taken to load and unload passengers at bus stops on and off the freeway.

A schedule average speed of 56 mi/h (90 km/h) is shown in Fig. 3 for rapid transit trains. It was calculated on the basis of the following arbitrary, but reasonable, assumptions:

1. Modern, high-speed transit trains, capable of operating at 80 mi/h (128 km/h), are used.
2. These trains can accelerate and brake at the rate of 3 mi/h/s (4.8 km/h/s).
3. Station stops are spaced 3 miles (4.8 km) apart.
4. Standing time at each station, for loading and unloading passengers, is 15 seconds (see Fig. 4).

Thus it is clear that rail rapid transit is capable by far of moving many more people much faster than any other proved form of transit. It is therefore logical that a rail rapid transit should form the core of any balanced transit system. Automobiles, buses, and streetcars should be used as feeder lines to feed or channel riders into the rapid transit system. In this way each form of transit is used for what it can do best.

Outlying rapid transit stations should provide ample parking for those riders who wish to drive their own cars to the "park-and-ride" station. Bus lanes should be conveniently located at these stations for those who prefer to take the bus to the rapid transit station. Special "kiss-and-ride" lanes should be provided for those who are driven to the station by their wives. Such stations are already in use to a limited extent in several North American and European cities.

Monorail systems

A few words should be said about monorail as a possible form of transit. Except in very unusual circumstances, monorail in any form is not at all suitable as a part of a rapid transit system since it has many disadvantages. Its only advantage is that it can be used to haul freight or passengers in areas where grading costs are prohibitive (such as narrow mountain gorges) and where speed and operating efficiency are not important.

Monorail may be one of two types: suspended or supported. The suspended type employs an overhead beam or rail from which the cars are suspended or hung. The supported type employs a rail or beam way, located below the cars. In the latter case, some form of guide rails or guidance by the supporting beam itself must be used for balance. Some of the many disadvantages of monorail are

1. The switching problem cannot be solved as simply as that of a conventional railroad switch because a monorail switch inherently requires a considerable space, uses a large amount of power, and takes a long time to operate.
2. The supporting structure must be used everywhere, even underground, and where conventional rail lines could operate better on the surface of the ground.

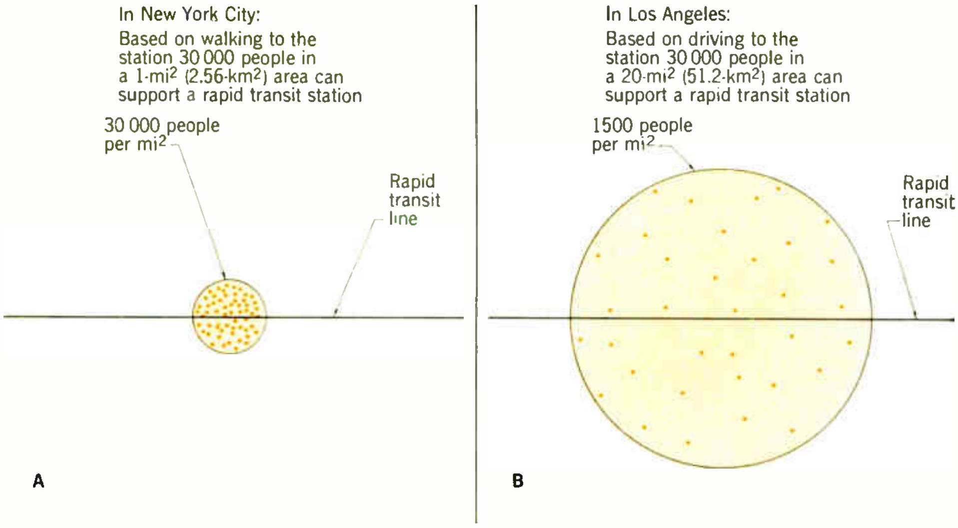


FIGURE 5. Pictorial representation disproving the "population density myth." A—High population density. B—Low population density.

3. For the suspended type, the car walls must be heavier and stronger than those of conventional railcars because they must support the entire passenger load, not just the roof.

4. The supporting structure of a suspended monorail must be higher and heavier, and must have larger foundations than the conventional elevated-type structure.

5. With the suspended type, the speed is severely limited by an inherent side-sway characteristic as, for example, the Wuppertal line in Germany, which cannot exceed 22 mi/h (35 km/h) for this very reason.

6. For the supported type, the guide rails necessary for proper balancing cause a bumpy ride, and this also limits speed.

7. Any type of monorail is completely incompatible with conventional railroads, thus making cooperation in times of emergency impossible.

The population density myth

Most existing rapid transit rail lines were built before the age of the automobile in areas of high population density where a sufficient number of riders could walk to the stations to support the lines. Thus, in those days, it was thought necessary to have a high population density in order to make a rail rapid transit line feasible.

Today, however, the picture is entirely different because we live in the age of the automobile; we can ride to the nearest rapid transit station by bus or automobile. Consequently, each station can support a larger area with a low population density. Station spacing can be increased, thereby extending and speeding up rapid transit service. Therefore, a high population density is no longer needed to support a rapid transit station.

Shown diagrammatically in Fig. 5 is an area served by a rapid transit line where the population density is (A) high, as in New York City; and (B) low, as in Los Angeles —or any other city that expanded greatly during the automobile age. Many people erroneously believe that rail rapid transit lines can be justified only in areas as depicted for New York City. The circle shown (A) represents an area of one square mile (2.56 km^2). The radius of the circle is 0.56 mile (0.9 km), and it represents the maximum walking distance to the station. If the population in this area is taken to be 30 000 then the population density is 30 000 people per square mile (12 000 people per km^2).

The area enclosed by the other circle (B) represents a low population density. The total population enclosed by the circle is taken again as 30 000. Assuming the area to be 20 square miles (51.2 km^2), the population density (B) is only 1500 persons per square mile (600 persons per km^2). The radius of the circle is 2.5 miles (4 km), and it represents the maximum driving or riding distance to the station. Thus, thanks to the availability of both the automobile and bus, both high- and low-population-density areas can be served by high-speed rail rapid transit lines.

The 'core' of balanced transit

Most people are quite familiar with what the automobile and bus can do well, but few realize what the high-speed rail rapid transit train can do best simply because there are limited existing examples of the efficient performance of rail rapid transit. There are several important features of modern rail rapid transit, which is sometimes referred to as the "core" of balanced transit.

First, a separated right of way, without any obstructions or hindrances, is necessary for truly efficient operation of a rapid transit line. This right of way may exist in one or more of several different forms: trains can operate underground, on the surface, on an elevated freeway-type structure, on an elevated earth embankment, in an open cut, in the median strip of a freeway, or along an existing railroad right of way.

A notable example of a rail rapid transit line situated in the median strip of a freeway can be found in Chicago. Overpasses that span the freeway provide access to rapid transit stations by means of pedestrian ramps, without interference to the freeway or tracks. In most cities, existing railroad rights of way radiate from the center in all directions, and they provide access directly to the center-city area. To be suitable for rapid transit, these rights of way must be free of grade crossings.

Further, high-speed transit equipment is essential for efficient service. High-speed equipment, now used experimentally in Chicago, is capable of attaining a speed of 80 mi/h (128 km/h). The performance of this equipment

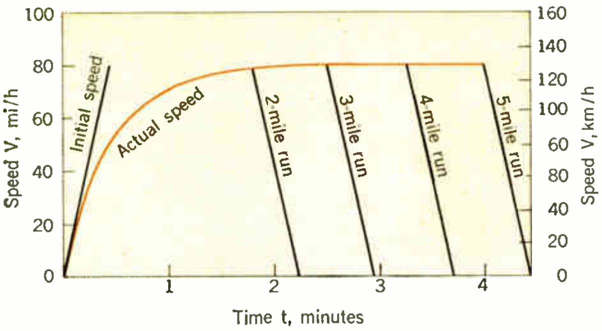
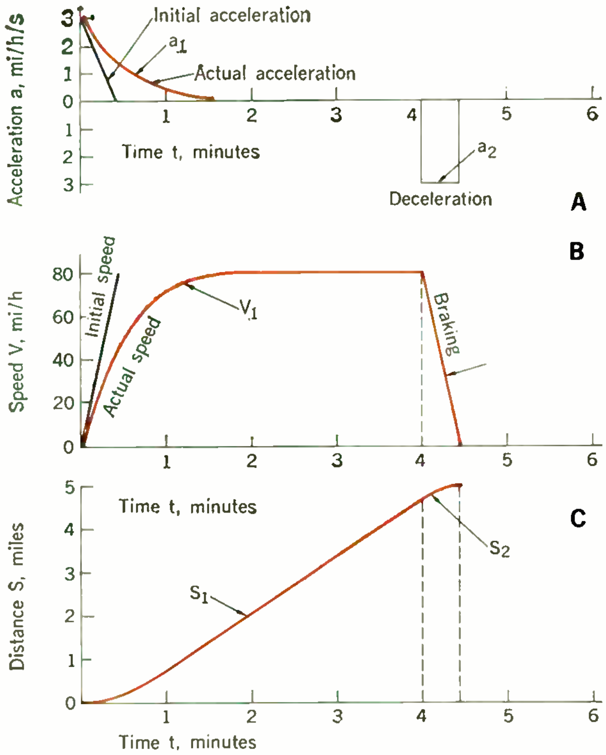


FIGURE 6. Speed–time curves for a rail transit run.

FIGURE 7. Acceleration (A), velocity (B), and distance (C) curves for a 5-mile (8-km) run with high-speed equipment.



is compared in Fig. 6 with more conventional equipment operating at 50 mi/h (80 km/h).

Acceleration, speed, and distance curves for a 5-mile (8-km) run with high-speed equipment are graphed in Fig. 7. The speed V_1 in km per hour is very closely approximated by the equation

$$V_1 = 128\,(1 - \epsilon^{-0.44t_1}) \tag{1}$$

where t_2 is the time in minutes during which power is applied. The speed V_2 in km per hour during braking is given by

$$V_2 = V_1\,(1 - 2.25\,t_2) \tag{2}$$

where t_2 is the time in minutes during which the brakes are applied. Differentiation of Eqs. (1) and (2), respectively, will give acceleration a_1 in km per hour per second during application of power as

$$a_1 = 4.8^{-2.25t_1} \tag{3}$$

and a_2 in km per hour per second during braking as

$$a_2 = -4.8 \tag{4}$$

Integration of (1) and (2) will give the distance traveled S_1 in km during application of power as

$$S_1 = 2.13\,[t_1 - \frac{4}{9}(1 - \epsilon^{-2.25t_1})] \tag{5}$$

and S_2 in km during braking as

$$S_2 = S_1 + 2.13\,t_2 - 2.4\,t_2^2 \tag{6}$$

Adequate station spacing must be provided for to take advantage of high-speed equipment. Figure 7 compares the schedule speed of conventional and high-speed equipment for various station spacings. All calculations are based on the assumption that the standing time at each station is 15 seconds for loading and unloading passengers. This time is ample if enough doors are provided and if station platforms are at the same level as car floors. It is clear from Fig. 8 that there is no advantage in using high-speed equipment unless stations are spaced sufficiently far apart. For a station spacing of 0.75 mile (1.2 km), the difference between the schedule speed for conventional and for high-speed equipment is very little. With a spacing of 3 miles (4.8 km), the schedule speed is 42 mi/h (68 km/h) for conventional and 56 mi/h (90 km/h) for high-speed equipment. At a 5-mile (8-km) spacing, these speeds increase to 44 mi/h (70 km/h) for conventional and 64 mi/h (104 km/h) for high-speed equipment.

High-speed rapid transit trains clearly outperform the automobile and bus, as well as the conventional equipment, as station spacing increases. Speeds higher than 80 mi/h (128 km/h) can be used where station spacing is sufficient to warrant it. Naturally, modern, high-speed equipment should be designed for comfort, attractiveness, quietness, and adequate ventilation as required. "Skip-stop" service may be used to speed up trains in areas where stations must be close together and where trackage is limited.

The foregoing equations can be used to calculate the effect of station standing time on schedule speed for various station spacings. This was done for station spacings of two, three, and five miles (3.2, 4.8, and 8 km), with the results shown in Fig. 4. It shows that a small increase in station standing time has very little effect as schedule speed drops from 56 mi/h (90 km/h) to 55 mi/h if the station standing time is increased from 15 to 20 seconds.

Automatic computer control can provide fail-safe train operation with far greater reliability and safety than is possible with the human operator, or motorman. With a computer-controlled system the only need for an attendant on the train is to monitor performance and to exert manual control in the event of an emergency. The same degree of automatic control employed in elevators can be applied to rapid transit trains. The operations of starting, stopping, and slowing down for curves can be programmed into the computer control system.

A modern rapid transit system should be compatible with standard railroads. Rapid transit trains should be able to operate on standard railroad tracks, and standard

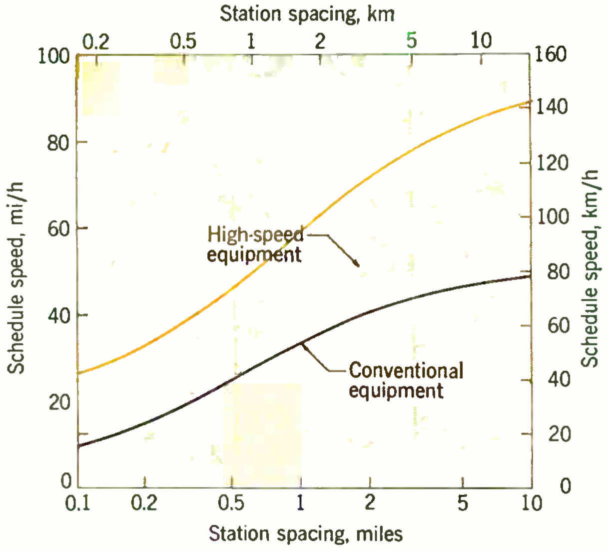


FIGURE 8. Graphic comparison of schedule speed versus station spacing for high-speed and conventional rail transit.

railroad equipment should be able to use the rapid transit tracks. This would enable standard railroads and rapid transit lines to cooperate in emergencies, such as in the evacuation of large numbers of people because of floods, storms, and other catastrophes.

More economical operation is possible for rail rapid transit than for automobiles or buses. Initial construction costs for a surface rapid transit line may be less than that for a freeway, because the latter requires much more space, especially at traffic interchanges. Experience in Chicago has shown that the installation of a rapid transit line in the median strip of a freeway adds only 5 percent to the original cost of the freeway itself.

In discussing freeway and rapid transit costs, Leland Hazard was recently quoted in *Metropolitan Magazine* as saying to a Pittsburgh audience: "The comparison in costs (between freeways and rail rapid transit lines) is shocking. An eight-lane freeway [four lanes in each direction] has a person–trip capacity of 9000 [based on 2250 persons per hour per lane] at a capital cost of $1670 per person. A subway or elevated express or local [train] has a person–trip capacity of 50 000 at a capital cost of $440 per person. Rapid transit does five times the work at one fourth the cost. What are we waiting for; or should we have our civic heads examined?"

Benefits of balanced transit

Everyone benefits from a balanced transit system, whether he takes advantage of it or not. The most obvious advantage of a balanced transit system is that it reduces traffic congestion. Freeways are left freer for those who must drive. Rail rapid transit, the core of a balanced system, it not affected by inclement weather.

The parking problem is greatly alleviated by a reduction in automobile traffic. It is obvious that valuable urban space used for parking is not available for commercial development. At present, the location of a new industrial plant or office building is often decided by the availability of parking space for the cars of the occupants.

A balanced transit system saves travel time for everyone. Figures 3 and 7 both show that a high-speed rapid transit train, which stands for 15 seconds at stations spaced 3 miles (4.8 km) apart, will maintain a schedule speed of 56 mi/h (90 km/h). This speed is higher than that attainable by the private automobile on freeways, particularly during rush hours. Even when freeway traffic is flowing smoothly, it still takes time to get to and from the freeway and to find a parking space reasonably near one's destination.

The rapid transit core of a balanced system will attract business where none existed before. This is pointed out in an observation in a recent issue of *The Financial Post* of Toronto: "Everybody gains when a busy city opens a new subway—subsidies to help build it are balanced rapidly and then absorbed by new property development which produces soaring assessments and thus higher tax revenues." When the central business section of a city is easier to reach, more business is attracted to the area. The same holds true for peripheral business sections, and thus prevents an increase in property taxes for landowners in outlying areas.

BIBLIOGRAPHY

Allen, C. J., *Modern Railways—Their Engineering, Equipment and Operation*. London: Faber and Faber, Ltd., 1959.

Amerine, J., "Prof says rail system better than freeways," *The Houston Chronicle*, Dec. 1965.

Becht, J. E., "The Fulshear line," *Univ. Houston Business Rev.*, vol. 13, pp. 1–45, Spring 1966.

Brecher, R. and E., "Getting to work and back," *Consumer Repts.*, vol. 30, pp. 56–65, Feb. 1965.

Chicago Area Transportation Study, vols. 1–3. Chicago: State of Illinois, 1963.

Chilton, E. G., "Research preparation for modern urban rapid transit," *Stanford Res. Inst.* (feature issue), pp. 19–22, Jan. 1965.

"Our city: start now to plan city's mass transit system, (editorial)," *The Houston Post*, Dec. 1965.

Connolly, W., "There's a limit to freeways," *The Houston Chronicle*, Dec. 1965.

DeMent, G. L., "1966 rapid transit review," *Inst. Rapid Transit News Letter*, vol. 7, Dec. 1966.

Harmon, G. M., ed., *Coordination of Service—Basis for an Improved National Transportation System*. Syracuse, N.Y.: Syracuse Univ. Press, 1964.

Heenan, G. W., "Rapid transit influences Toronto real estate values," *Going Places*, pp. 8–9, Fourth Quarter, 1966.

Herbert, E., "Transporting people," *Intern. Sci. Technol.*, vol. 46, pp. 30–42, Oct. 1965.

Karmin, M. W., "Transit troubles," *The Wall Street J.*, p. 1., May 26, 1965.

Keefer, L. E., "Shaping the demand for mass transportation," *Traffic Quarterly*, pp. 589–596, Oct. 1964.

Michaels, E. L., "The need for balanced transit in the U.S.A." (in Finnish), *Arkkitehti Arkitekten*, July–Aug. 1965.

Michaels, E. L., "Rapid transit in Stockholm," *City and Suburban Travel*, Nov. 1958.

"Montreal's achievements in rapid transit," *Inst. Rapid Transit News Letter*, vol. 8, Apr. 1967.

Quinby, H. D., "Major urban corridor facilities: a new concept," *Traffic Quarterly*, p. 242, Apr. 1962.

Reich, S., "Computer simulation for rapid transit," *Instr. Control Sys.*, vol. 39, pp. 101–103, Oct. 1966.

Reinsberg, M., *Growth and Change in Metropolitan Areas and Their Relation to Metropolitan Transportation*. Evanston, Ill.: Northwestern Univ. Press, 1961.

Ross, H. R., "New transportation technology," *Intern. Sci. Technol.*, pp. 26–27, Nov. 1966.

Schroeder, W. W., *Metropolitan Transit Research*. Chicago: Chicago Transit Board, 1955–1956, chaps. 6, 11.

Seip, N. W., *The Key to Better Living—Balanced Transportation*. Bloomington, Ind.: Indiana Univ. Press, Nov. 1964.

Weaver, R. C., "The federal interest in urban transportation," *Traffic Quarterly*, p. 24, Jan. 1963.

FIGURE 1. The IEEE Headquarters staff.

"IEEE Headquarters"—people, facilities, and functions

Since the operations of the Institute staff reflect the whole range of IEEE activity, this review provides an important insight into the nature of our Society

Donald G. Fink *General Manager, IEEE*

At the close of IEEE's fifth year, with the transitions and adjustments of the merger now largely behind us, it is timely to review the organization that mirrors the Institute as a whole—the Headquarters staff. "Headquarters" is a word of many meanings, which reflect the particular interests and involvements of individual members. Thus, to Section officers everywhere Headquarters is largely identified with Emily Sirjane, who faithfully responds to their many questions and requests. To IEEE Group people, the name of the Headquarters game is Dick Emberson. Authors, editors, and reviewers of IEEE papers tend to equate "New York" with Woody Gannett. Their departments serve a multitude of "members at a distance," most of whom do not have the opportunity to visit Headquarters.

Equally vital tasks are performed largely within Headquarters by equally devoted people, and behind each of the staff leaders are many others who carry out the details of staff assignments. In all, as this is written, the IEEE Headquarters staff is comprised of 268 permanent members and, in addition, some 23 temporary employees (Fig. 1).

Who runs the show?

As preamble, it is well to correct a misconception that is widely held: that Headquarters "runs" the Institute. The word Headquarters, as often used, includes not onl the staff, who do not "run" things, but also the IEE officers, directors, committeemen, and other voluntee officials who do indeed run the show. The distinction is

vital to a proper understanding of the staff functions. The Institute is governed, its policies set, its future plans made, its progress and problems assessed, its recognition extended—not by staff people but by the more than 25 000 elected and appointed officials of IEEE who serve on its 2000 boards, committees, and subcommittees (see adjacent box).

The staff job is to understand, interpret, and implement the decisions and policies established by these officers and committee members. This does not mean that the influence of the staff on Institute policy is negligible. Bringing problems to the attention of the policy makers and day-by-day interpretation by the staff of existing policies have a strong influence on the way that IEEE's affairs are conducted.

Headquarters organization

The chart given in Fig. 2 shows the organization of the staff. Headquarters operations are guided by the IEEE Executive Committee, which consists of six IEEE officers and three other members of the Board of Directors. These men meet monthly to deal with policy matters affecting Institute operations in all its phases. They are the boss of the General Manager, who in turn is responsible for directing the Headquarters staff.

The members of the Executive Committee direct IEEE affairs through assignments based on 15 principal standing boards and committees of the Institute. Each member serves as "Coordinator" for one or more of these committees (Fig. 3). The President serves as a "Coordinator-at-Large" and is prepared to take a hand in any matter not otherwise assigned.

IEEE's committees and subcommittees comprise—

In Institute government:	Memberships
Boards and committees composed of Directors or appointed by them	387
Subordinate committees and subcommittees of the above	402
In locally organized units (estimated):	
Regional committees	220
Section, Subsection, and Council Executive Committees	940
Subcommittees of the above	5 800
Group Chapter committees	8 670
Student Branch committees	1 200
In the IEEE Groups:	
Group Administrative Committees	1 024
Technical committees and subcommittees of the Groups	7 337
In other organizations:	
Representatives to outside organizations	545
In IEEE Conferences:	
Conference committees and subcommittees	5 384
Total	31 909

Note: Many IEEE members serve on several committees. It is estimated that at least 25 000 different people are involved in the IEEE committee work listed above.

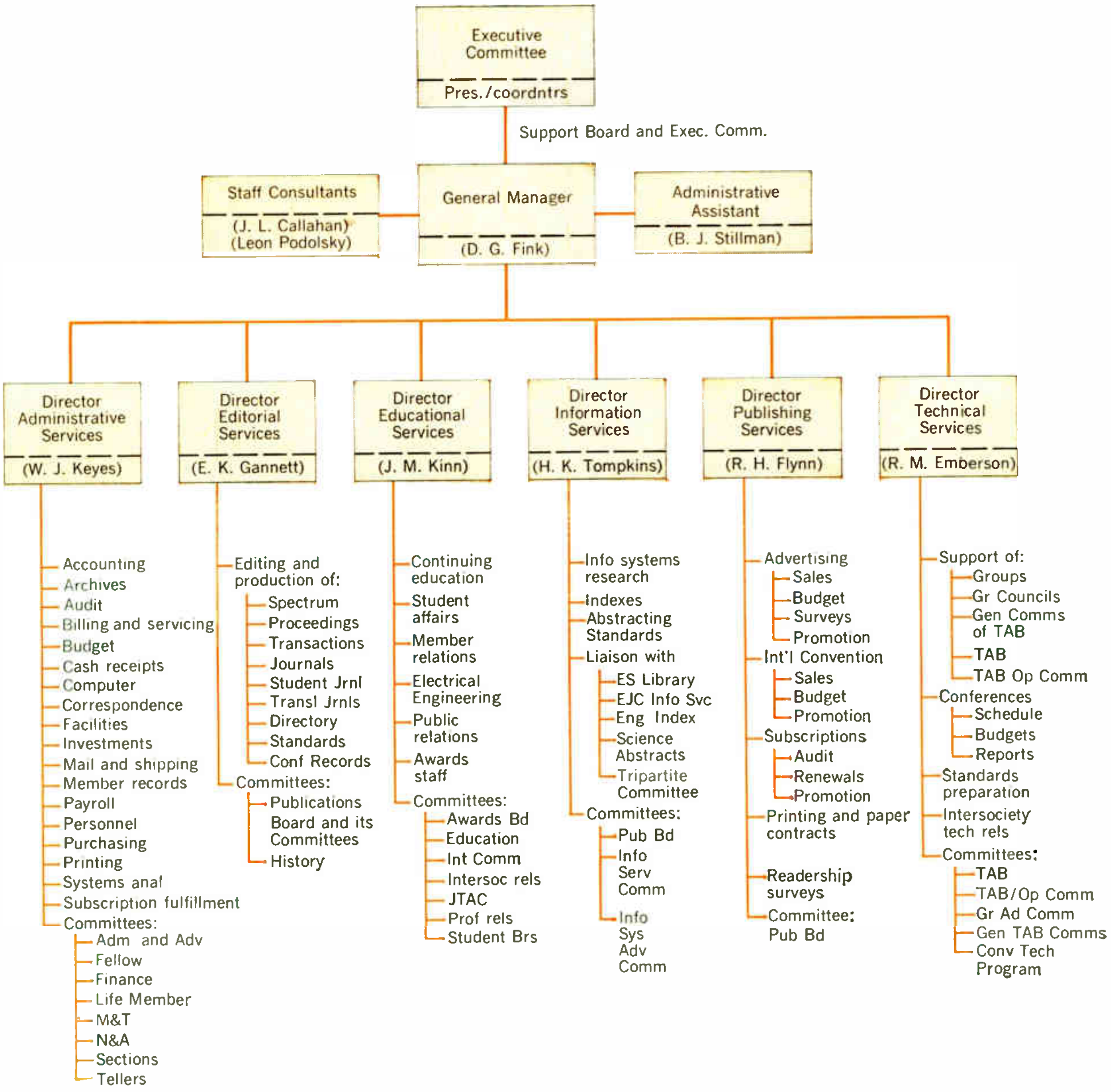


FIGURE 2. Headquarters staff organization chart.

The General Manager's job, so far as responsibilities upward are concerned, is to maintain active contact with the Coordinators and, through them, to support the Executive Committee and the Board of Directors in all their work. The General Manager is also expected to be in touch, either personally or through his lieutenants, with everything that IEEE does, large and small, local and worldwide.

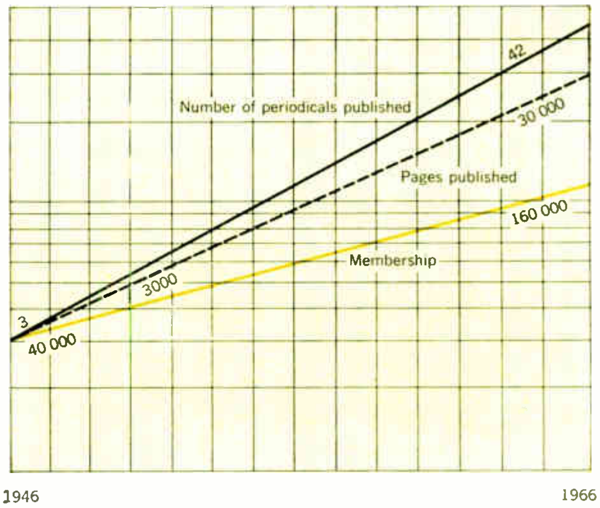
Reporting to the General Manager are the six Staff Directors, arrayed across the center of the organization chart. The allocation of responsibilities among the Staff Directors is indicated by their respective titles: administration, editorial, education, information, publishing, and technical services. These assignments are further defined by the activities listed under each Director. At the bottom of each column are listed the committees assigned to the respective Director. Each of these committees and boards has a Staff Secretary who prepares minutes, handles correspondence, and serves as the Headquarters point of contact. The Staff Director serves this function personally in a number of cases; otherwise the Staff Secretary reports directly to him. In all these functions the staff member's job is to help IEEE members achieve their objectives, while operating within the policies laid down by "the management," the Board of Directors and its subordinate units.

Not drawn on the chart are dashed lines that would reveal (were it not for the fact that they would obscure everything else) the interrelations among the six staff departments. Thus Editorial Services and Publishing Services together have the responsibility for publishing, on a common schedule, the technical and advertising pages of IEEE SPECTRUM and the PROCEEDINGS. The Group Activities in Technical Services are closely associated with the Editorial and Publishing Departments in matters affecting the Group Transactions and Journals and with the Administration Department in the maintenance and use of the Group mailing lists. Other lines connect each department with the General Manager, particularly when conflicting priorities arise.

Coordinator	Incumbent
Admission and advancement	Oliver
Awards	Knapp (Chrmn Awards Board)
Education	Oliver
Employee benefits	Granger
Finance	Granger (Treasurer)
History	Knapp
Internal communications	Chestnut
Intersociety relations	Shepherd (Chrmn IR Comm)
Memberships and transfers	Blackmon
Nominations and appointments	Oliver (Chrmn N&A Comm)
Professional relations	Chestnut
Publications	Willenbrock (Chrmn Pub Bd)
Sections	Blackmon (Chrmn Sections Comm)
Student Branches	Blackmon
Technical activities	Herwald (Chairman TAB)

FIGURE 3. Executive Committee Coordinators.

FIGURE 4. IEEE 20-year growth curve.



The appeal of organization charts is limited at best, but for the reader who has an interest in Headquarters operations, your General Manager knows of no better presentation. For the reader who has reason to visit or write Headquarters, this chart may serve as a road map to the Staff Director who can serve his particular interests. The names of the Staff Directors and the Staff Secretaries are published monthly on the organization page of IEEE SPECTRUM (page 4, this issue).

IEEE's dimensions

Not revealed by the organization chart is the scale of operations: the size of the membership, the diversity of organization, the rate of growth, the scope of technical conferences and publications. By any standard, IEEE's dimensions in each of these categories are large and the staff support required is large in proportion.

Figure 4 illustrates the 20-year trend in two dimensions—membership and publication activity. In 1946, AIEE and IRE together had about 40 000 members, and published in three journals a total of 3000 editorial pages. By 1966, the membership had increased fourfold, the number of periodicals had risen to 42, and the two societies, merged as IEEE, were publishing ten times as many editorial pages (Fig. 5).

The organizational diversity has followed the same trend. In 1946, the Group system was in the planning stage; today there are 31 Groups producing 31 Group Transactions, two Group Journals, and a host of Conference Records, newsletters, conference programs, and

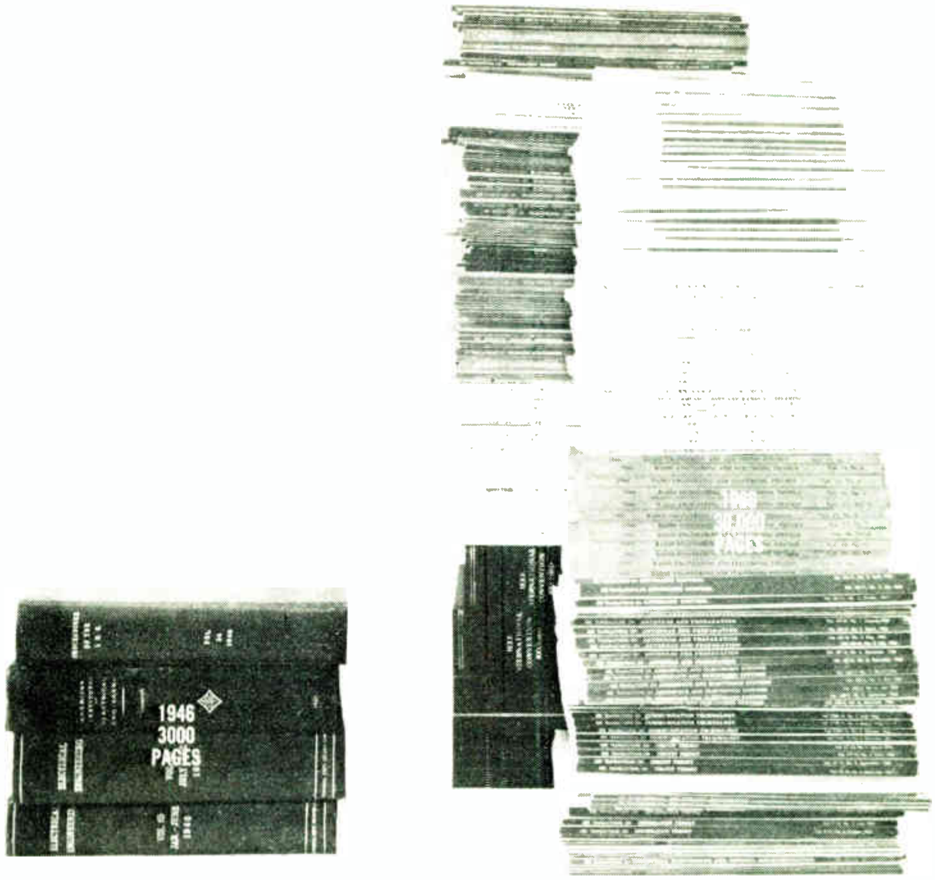


FIGURE 5. Publications, 1946 versus 1966.

other announcements. The traditional groupings of IEEE members by geography (Sections, Subsections, Group Chapters, Student Branches) have similarly proliferated. The count of these locally organized units, at the end of 1966, was 994! Additions, in 1967, particularly in Group Chapters and Student Branches, have pushed IEEE well over the 1000 mark in local units. To support such an organization, decentralization of authority and responsibility is a must. Each IEEE unit depends, however, directly or indirectly on guidance from Headquarters, if only to interpret particular situations not covered in the Section, Group, and Student Branch manuals.

The number of IEEE conferences has kept pace with these trends. In 1966, IEEE was sponsor or cosponsor of 97 major conferences with a total attendance of over 200 000. Even when the larger regional conferences and the IEEE International Convention are not counted, and attention is focused on conferences of special technical content, the average attendance was over 700.

Indeed, IEEE's dimensions are large. The accompanying boxes, which cite statistics on the volume of work handled by the IEEE Computer Center, the Mail Room, and the Editorial Office, reveal the impact on Headquarters operations.

IEEE's Computer Center

- Prints out 11 900 000 mailing labels per year
- Computes and prints 326 000 bills and follow-up notices for dues and fees
- Keeps track of 175 000 home addresses of members for mailing and 120 000 business addresses for directory compilation
- Updates, on an average, 20 000 master file entries per week
- Makes 4100 selections per year from the master file for Section, Group, and other IEEE unit mailings
- Tabulates 40 300 votes cast in the annual ballot for officers and Directors
- Prepares 265 statistical reports on membership and finances each year
- Uses six tape handlers, 16 384 words of core memory, and 18.8 million characters of disk storage; punches cards at the rate of 100 per minute and reads them at 400 per minute

IEEE's Mail Room

- Handles nearly a million pieces of outgoing mail per year, an average of 3800 each working day
- Receives, at peak load, 7500 pieces of general mail per day
- Distributes an average of 185 letters per day addressed to particular staff members or departments
- Pays out $80 000 per year in first-class postage, $63 000 in other classes
- Uses automated equipment for envelope insertion (capacity 6000 per hour) and label affixing (15 000 per hour)
- The foregoing figures do not include mailing IEEE periodicals, which are sent out by the printer. The postage for publications amounts to $191 000 per year

IEEE's Editorial Office

- Produces 58 IEEE periodicals and other publications having a combined distribution of 3 800 000 copies per year
- Processes 17 000 pages of manuscripts and proofs each month
- Produces each year 1500 manuscript pages of feature articles, news, and other staff-prepared copy
- Maintains contact with 480 editors and reviewers and 4000 contributors to IEEE publications in an average year
- Supervises, with the Publishing Department, printing bills totaling $2 900 000 per year, representing the cost of 40 million printing-press impressions on 1800 tons (36 carloads) of paper
- Prepares 40 000 illustrations for publication each year

IEEE members can be proud of the competance and dedication of the Institute staff. Headed by a Past President of the Institute with top-level editorial and industrial laboratory management experience, the staff has steadily increased in ability and effectiveness. At the same time it has been able to reduce its size through prudent consolidation and improved procedures. I am immensely impressed with the personal interest shown by each staff member in Institute affairs and in membership service. We have a valuable asset for which the entire Institute is profoundly grateful.

Walter K. MacAdam
President, IEEE

Facilities

Headquarters occupies 39 460 square feet of space on the 1st, 9th, 10th, 11th, 15th, and 16th floors of the United Engineering Center on 47th Street just north of the United Nations buildings in New York. This 18-floor building is one of which IEEE members can be particularly proud. Built from funds contributed by many individuals, societies, and institutions, this modern edifice now houses, in addition to the IEEE staff, the headquarters of 21 other engineering societies and intersociety organizations, all of which benefit from its excellent facilities and moderate rental cost.

Mail-handling equipment and storage space for records and back issues of publications are maintained in the basement of the Engineering Center and in a nearby annex on 46th Street. The IEEE's main reception desk is on the tenth floor, where the General Manager's office and the Technical Services, Educational Services, and Publishing Services Departments are located. The Editorial Services and Information Services Departments are located on the 11th floor. Administrative Services, the largest department, occupies the 15th and 16th floors, and the Computer Center is adjacent to the lobby on the first floor. Further perspective on the scale of IEEE operations can be gained from the fact that, although our Institute is one of 12 engineering societies in the Engineering Center, it occupies 33 percent of the floor space devoted to the staff operations of these societies.

The equipments maintained at Headquarters range from the computer (see box on page 96) to such mundane items as 310 file cabinets, 185 typewriters, and 300 desks. More specialized equipment includes seven key punches and four verifiers for entering data in the computer master file, a microfile reader, a comprehensive set of tape recording and projection equipment (donated as a memorial by friends of the late Past President L. F. Hickernell for use by committees), a typewriter whose characters can be read by optical scanners, and a massive 70-cubic-foot membership file, in which the "history card" of every member (printed out by the computer) is kept, and to which reference is made an average of 350 times a day.

Particularly important to the committeemen of the Institute are the facilities for meetings. The Board Room on the tenth floor (divisible into two rooms by an accordion-pleat divider) is the primary seat of committee work. Additional rooms on the first and ninth floors are available. In all, some 400 IEEE meetings are held in these rooms each year. The receptionist on the tenth floor keeps track of the meeting schedule and is prepared to supply information as to what meeting is being held where.

People

What manner of people sit at Headquarters? The writer feels qualified by his five years in the job of General Manager to hand down this verdict: the best in the business. Lest this be dismissed as a prejudiced view, IEEE President MacAdam's comments appear in the box at left. Space permits only a review of the background of the six Staff Directors, and a listing of their right-hand men and women.

Richard M. Emberson—Technical Services

Dick Emberson joined the IRE staff three months before the merger, in October 1962, having been recruited

by the late Past President Lloyd M. Berkner. By training a physicist (Ph.D. degree from the University of Missouri, 1936), Dick is by persuasion and experience a master supporter of technical people and their programs. One of his assignments is to "get the most" for the IEEE Groups and in this pursuit he is unswerving, as the Group Chairmen will testify. Actually, Dick's work extends beyond the Groups proper into the broad area of IEEE's whole technical program, including the interfaces with the Sections and Regions. His office publishes the IEEE Master Meeting Schedule, issued quarterly, and maintains contact with 100 conference committees, to coordinate programs, dates, places, and budgets.

Dr. Emberson acts as Staff Secretary of the Technical Activities Board and its Operating Committee. A Fellow of IEEE, he has a well-earned reputation as an authority on such matters as the use of the spectrum for radio astronomy. He has been a delegate to CCIR conferences in this field on several occasions.

Reporting to Dr. Emberson are: Patricia Corcoran, his Administrative Assistant; John J. Anderson, Staff Secretary of the Standards Committee; Mel Bonaviso, Group Accounts and Commitments; William P. Layton and Edwin D. MacDonald, Supervisors of Conference Services; and Howard Schumacher, Manager of Technical Services.

Ralph H. Flynn—Publishing Services

Ralph Flynn joined the staff in November 1965, bringing a wealth of experience in the business aspects of the printed word. From 1947 to 1954 he served as Publisher of *Electrical World* and had previous experience on the publishing staff of *Electronics*. His roots thus lie deep in the industries represented by the middle "EE" in IEEE. Ralph was graduated from the University of Southern California in 1930 with a degree in chemical engineering. In addition to his sales and publishing experience in the technical field, he has served as a consultant to many companies on the inauguration and guidance of publishing properties. From 1963 to 1965 he served as publishing consultant to IEEE.

As Fig. 2 shows, Mr. Flynn has many responsibilities beyond IEEE's advertising program, notably the business aspects of the IEEE International Convention. Reporting to him is IEEE's Advertising Manager and International Convention Manager, William C. Copp.

Elwood K. Gannett—Editorial Services

In point of service, Woody Gannett is the senior Staff Director, at age 44. He joined IRE in August 1946 as Administrative Assistant to the Executive Secretary, having been graduated from the University of Michigan in 1944 with a B.S. degree in electrical engineering. His span thus covers the great expansion in editorial output shown in Fig. 4. As head of the IRE and IEEE editorial staff since 1949 he has participated in the inauguration of all the Group Transactions and Journals and of IEEE SPECTRUM. During the many years he wrote "Scanning the Issues" (in which he summarized the content of all IRE publications), Woody read and, as much as any one man could, *understood* more technical copy than any other person living or dead. He is an IEEE Fellow.

Mr. Gannett is Staff Secretary of the Publications Board. Reporting to him is a staff of 62 people. His direct lieutenants are: Helene Frischauer, Administrative Editor; Patricia Penick, Administrative Assistant; R. K. Jurgen, Managing Editor of IEEE SPECTRUM; W. R. Crone, Managing Editor of PROCEEDINGS and Staff Secretary of the History Committee; A. A. McKenzie, Managing Editor of the STUDENT JOURNAL and Staff Secretary of the IEEE Translated Journals Committee; and E. C. Day, Manager of Dictionary Production.

W. J. Keyes—Administrative Services

Bill Keyes is a rarity among men of financial background: a generalist who understands the purposes of the IEEE programs and insists that the mechanisms of control be administered to support, not hinder, those purposes. He joined IEEE in February 1964 (introducing him to the General Manager has proved to be the most important service yet rendered by IEEE's auditors, Price Waterhouse and Company). As a New York State Certified Public Accountant, he knows financial planning and supervision in detail, but his tasks (Fig. 2) go far beyond this. He has proved particularly adept in organizing and directing the six managers who report to him. Bill was Comptroller of Weston Electrical Instruments before joining the IEEE; he received his bachelor's degree from Pace College in 1949. To him, more than any other individual on the staff, goes the credit for full, accurate, and timely reporting of where all IEEE organizational units stand, not only in dollars, but in the structure of tasks supported by those dollars.

Mr. Keyes is Staff Secretary of the Finance Committee. Reporting directly to him are: Emily Sirjane, Manager of the Membership Services Department and Staff Secretary of the Fellow, Membership and Transfers, Nomination and Appointments, and Sections Committees; Mike Asselta, Manager of the Office Systems Department; Tom Bartlett, Manager of the Accounting Department; John Buckley, Manager of the Treasury Department and Staff Secretary of the Employee Benefits Coordinating Committee; Jack Fraum, Manager of the Electronic Data Processing Department; and Ray Mendolia, Manager of the Operations Department.

J. M. Kinn—Educational Services

The growing role of the Institute in the continuing education of its members led, in 1965, to the creation of a new staff department to cover educational activities. Jack Kinn joined Headquarters in March of that year to coordinate staff support in this and the related field of student activities. Mr. Kinn was graduated in 1949 from the University of Missouri, with a B.S. degree in electrical engineering. His career has included an assignment at the Bell Telephone Laboratories, and editorial work on *Electronics* and the *IBM Journal of Research and Development*. He was Manager, Scientific Information, at IBM Corporate Headquarters before joining the IEEE staff. He is responsible for staff support in the fields of intersociety relations, internal communications, public relations, professional relations, the IEEE Awards program, and the Joint Technical Advisory Committee.

Reporting to Mr. Kinn, in charge of staff support of student affairs until his untimely death in September of this year, was Lawrence D. Leonard. Mr. Kinn's lieutenants are: Patricia Olds, Administrative Assistant; Audrey Van Dort, Administrative Assistant for JTAC and Staff Secretary of the Internal Communications Committee; Una Lennon, Staff Secretary of the Awards Board; and Emma White, Acting Staff Secretary of the Student Branches Committee. Mr. Kinn serves as Staff Secretary of the Education Committee, Intersociety Relations Committee, Professional Relations Committee, and JTAC.

H. E. Tompkins—Information Services

The great outpouring of technical literature, illustrated in Fig. 4, has required improved methods of identifying, selecting, and disseminating publications. This year the Executive Committee authorized the creation of a new department, Information Services, specifically to deal with such matters as the indexing, abstracting, storage, retrieval—in brief, rational organization for use—of the IEEE literature and its interfaces with other fields. The Institute was fortunate to obtain the services of Dr. Howard E. Tompkins to head this staff function. He joined the IEEE staff in July of this year, leaving his position as head of the Department of Electrical Engineering at the University of Maryland. His career also includes positions with the Philco Corporation, the Burroughs Corporation, and the National Institutes of Health, and faculty appointments at the Universities of Pennsylvania and New Mexico. He is widely recognized as a leader in the field of information science and use of computer methods. He obtained his Ph.D. degree in electrical engineering from the University of Pennsylvania in 1957.

Although only a few months have passed since Howard joined the staff, he has already arranged for a new and comprehensive method of indexing the IEEE Group Transactions and Journals using computer methods—the start of an automated data base that will grow in the future to include all IEEE publications and to fit logically into the several indexing and abstracting services with which IEEE is affiliated. Reporting to Dr. Tompkins is Anita Sedler, Administrative Assistant. Dr. Tompkins serves as the Staff Secretary of the Information Services and the Information Systems Advisory Committees.

General Manager's Office

The General Manager's right-hand woman is Betty Stillman, his Administrative Assistant. Betty, who earned her B.A. degree at Roanoke College in 1948, joined the staff in 1963. In 1964 she was transferred to take on the demanding duties of recording the minutes of the meetings of the Board of Directors and the Executive Committee and preparing such follow-through documents as five to ten pages of "action items" that demand the attention of the General Manager and the Staff Directors following each meeting. Betty also supervises the secretarial staff that ably keeps the General Manager abreast of his personal correspondence, which currently runs to nearly 4000 individually dictated and signed letters and carbon copies each year. Concerning the General Manager, data appear on page 41 of this issue.

As can be imagined, the General Manager is sometimes called upon to moderate conflicting priorities among the six departments, but in his prior careers in publishing and industrial research he has never seen a smoother-working team. All their functions have one end—to help IEEE members achieve their objectives, within the policies laid down by "the management," the Institute's volunteer officials. So far as its own impact on IEEE operations is concerned, the staff is at one with Emerson, who wrote, "The less government we have, the better!"

Questions?

In reviewing this article, your General Manager is impressed by how much could have been said but cannot be accommodated in space reasonably assigned to the subject. The reader, referring once again to the functions listed in Fig. 2, may find operations he would like to know more about. A letter addressed to Don Fink on any such questions will be most welcome.

Conference on Electron Device Research: A pattern to be copied?

For over a quarter of a century, in spite of the general proliferation of conferences on almost every device (and subsequent application) discussed by CEDR, this group has remained the most viable in the field

Charles Süsskind *University of California, Berkeley*

The recent meeting of the Conference on Electron Device Research at McGill University in Montreal (June 21–23) was the 25th in a series of meetings of a group whose composition and activities epitomize one of Derek Price's "invisible colleges."[1] Predominantly made up of electronics engineers and applied physicists, the group has met annually since 1939 (Table I; there was a hiatus during World War II) under conditions even more stringent than those that govern the famed Gordon conferences in New Hampshire and elsewhere.

The CEDR is a closed conference—attendance is by invitation only, and the international list is continually culled by a committee member who is instructed to be ruthless in keeping it down to a few hundred of the most active workers in the field. Formal papers are presented, but no proceedings, preprints, or even abstracts are ever distributed (except to the papers committee, which makes its selections on the basis of abstracts). Statements made and results cited cannot be quoted without the author's express permission. No reporters are admitted, and the practice of photographing slides from the display screen is proscribed. Most important of all, authors are enjoined to limit themselves strictly to previously unpublished results; not infrequently, work completed only a few days before the meeting is described. The last half-day is customarily given over to "rump sessions"—completely impromptu presentations and frank, detailed discussions. The university *ambiance*, with most delegates housed in dormitories, contributes to open exchange.

As a result, CEDR has a standing and prestige among electron-device specialists that is unmatched by any other meeting. Authors, ranging from young men about to complete their doctoral work to heads of large teams at famous industrial research laboratories, would much rather submit a paper to CEDR than to national meetings of their professional societies, and will cheerfully battle the corporation patent departments of a notoriously close-mouthed industry for permission to disclose latest results—an endeavor in which the published rules of the meeting have been of great help. The few hundred active participants form a uniquely viable peer group that has evolved an efficient method of continually updating not only its membership, but also the subjects of its deliberations.

The conference, which was under joint AIEE–IRE sponsorship long before the two societies decided to merge into IEEE, was first constituted at the initiative of such electronics "greats" as W. G. Dow, Harley Iams, F. B. Llewellyn, G. A. Morton, L. S. Nergaard, W. B. Nottingham, A. L. Samuel, J. Browder Thompson, and

Irving Wolff; F. R. Lack was the first chairman and H. P. Westman the first secretary.[2] It met in New York City (for the first and last time) in 1939 and twice more (at the Stevens Institute of Technology in Hoboken, N.J.) before World War II intervened. The three topics for the first meeting were electron optics, high-transconductance devices, and ultrahigh-frequency electronics.[2] The principal concerns were the limitations of conventional electron tubes in frequency, power, and noise. After the war, these interests inevitably led to research papers on microwave tubes and, to a lesser extent, storage and display tubes.

Microwave tubes dominated the postwar meetings. First announcements of a number of important inventions and discoveries were made at these sessions. The first disclosure of Rudolf Kompfner's traveling-wave tube was made by his associate, Joseph Hatton, during the 1946 meeting at Yale.[3] The discovery of backward-wave operation, the basis for an important class of voltage-tunable microwave oscillators and amplifiers, was first announced simultaneously by Kompfner and by Epsztein at the 1952 meeting in Ottawa. The first coaxial magnetron was described by Joseph Feinstein at the 1955 meeting at Michigan State University. Other firsts are listed in Table I.

Electron tubes did not remain the sole topic for long, however, although all hands admit that the traveling-wave tube, at any rate, held the center of the stage for a long time. (At the 1967 meeting, one lone paper on a traveling-wave tube was presented, by R. W. Gerchberg.) "How can a lot of intelligent people have taken ten years to do this rather narrow thing?" asks J. R. Pierce,[4] who did more than any other engineer to develop Kompfner's invention. But at the 1952 meeting in Ottawa, when research on microwave tubes was in its heyday, Joseph Weber of the University of Maryland presented a paper on the maser that even C. H. Townes, who shared the 1964 Nobel prize in physics with the U.S.S.R.'s N. G. Basov and A. M. Prokhorov for their work on the maser, freely admits was an independent discovery of part of the principle that underlies all maser and laser operation. And in 1948, the first technical discussion of the newly invented transistor took place at the Cornell meeting.

That invention signaled the end of the virtual monopoly of the "tube boys" on interesting new work in electron devices. During the 1951 meeting at the University of New Hampshire, the transistor papers and the people interested in them formed such clearly separate groups that a schism was inevitable and a new meeting was organized, the Solid-State Device Research Conference, which has been meeting under substantially identical rules ever since. In the meantime, the attention of the original group was shifting from tubes to gaseous-plasma devices, masers and lasers, and solid-state devices other than transistors. George Feher first described the two-level solid-state maser at the 1956 meeting in Boulder, Colo.; and at the 1957 meeting in Berkeley, Calif., Marion Hines reported on the varactor diode—the first working electronic parametric amplifier, a device that has far outdistanced the maser as the low-noise amplifier most frequently used in applications ranging from radar to radio astronomy. More recently, lasers and phonon interactions in solid-state materials have tended to dominate the programs. The subject of lasers is also very much in evidence at the spun-off solid-state device conference, and authors have been known to submit identical papers to both conferences. Next year, the two conferences plan to meet at the same location (in Boulder) during the same week, with one overlapping day of joint meetings, a move that may foreshadow ultimate reunification of the two groups.

The Conference on Electron Device Research has remained an important force for more than a quarter of a century despite split-offs and the general proliferation of conferences to a point where there is a massive, separate meeting on almost every device discussed by CEDR and another on its application. (For example, the biannual International Quantum Electronics Conference, largely devoted to lasers, drew 1200 at its last meeting in Phoenix in 1966; its offshoot, the Conference on Laser Engineering and Applications, drew 1400 to its first meeting in Washington in 1967.) The fact that CEDR has remained not only the most viable, but also the most influential and prestigious meeting in the field, suggests that this particular "invisible college" has found the key to its self-per-

I. Twenty-five Conferences on Electron Device Research, 1939–1967 (called Conference on Electron Tube Research until 1960)

No.	Year	Location	Some Important Firsts
1	1939	New York, N.Y.	Velocity modulation (Hahn) Capacitance analysis of triode (Dow) Transit-time effects in diodes (Llewellyn)
2	1939	Stevens Inst. Tech., N.J.	
3	1940	Same	
4	1946	Yale U., Conn.	Traveling-wave tube (Kompfner, Pierce)
5	1947	Syracuse U., N.Y.	"Kompfner dip" (Kompfner)
6	1948	Cornell U., N.Y.	Technical discussion of transistor (Shockley)
7	1949	Princeton U., N.J.	Noise conservation in electron beams (Pierce)
8	1950	U. Michigan	Noise space-charge waves (Cutler and Quate)
9	1951	U. New Hampshire	Kinetic power theorem (Chu)
10	1952	Ottawa, Canada	Amplification by inverted population (Weber) Backward-wave tubes (Epsztein, Kompfner)
11	1953	Stanford U., Calif.	
12	1954	U. Maine	
13	1955	Michigan State	Coaxial magnetron (Feinstein)
14	1956	U. Colorado	Two-level solid-state maser (Feher)
15	1957	U. California (Berkeley)	Varactor parametric amplifier (Hines) Low-noise electron gun (Currie and Forster)
16	1958	U. Laval, Quebec, Canada	
17	1959	U. Mexico, D.F.	DC pumped beam-type parametric amplifiers (BTL group)
18	1960	U. Washington (Seattle)	
19	1961	Rensselaer Poly. Inst., N.Y.	Microwave modulation of light (Kaminow)
20	1962	U. Minnesota	6328-Å He-Ne laser (White and Rigden)
21	1963	U. Utah	
22	1964	Cornell U., N.Y.	Mode locking in lasers (BTL group) Ion lasers (Bridges)
23	1965	U. Illinois (Urbana)	
24	1966	Caltech, Calif.	
25	1967	McGill U., Canada	Parametric fluorescence (Harris)

petuation by evolving a meeting format that other groups might do well to copy. Kompfner puts it more strongly. "If the space boys had a conference such as this one," he said recently, "limited in attendance and not plagued by petty jealousies among competing firms, the U.S. would be as far ahead of the Soviet Union in space technology as it is in electronics!"

One prerequisite is a common philosophy. Why do certain authors persist in submitting first-class, up-to-date papers on lasers, plasma and superconducting devices, or acoustic-wave microwave interactions to CEDR rather than to some competing meeting devoted to that specific topic? What has the CEDR group in common? Essentially, there is still the same interest in making things work at higher frequencies, higher powers, and lower noise levels. Robert Adler, research vice president of Zenith and a prolific CEDR contributor (the invention of his tube-type parametric amplifier would have been an epoch-making advance in the low-noise field if it had not been eclipsed by Hines' solid-state version in the very same year), sees the *wave* approach as the common thread. "CEDR could be called the $e^{j(\omega t-kz)}$ electron-device conference, " he says. "We like to describe things in terms of periodic variations in time and space. We are not comfortable with junctions. The transistor and MOS people are uncomfortable when waves are mentioned. To us, wave concepts are a common language, a key to the understanding of each other's work."

Another factor that imitators of CEDR might have to look for is the backing of an influential research group. For CEDR, that has unquestionably been the Bell Telephone Laboratories from the start. At the 25th meeting, BTL engineers presented more papers than the next three strongest participating groups together (the electrical engineering departments of Stanford, University of California at Berkeley, and M.I.T.). That is not to say that BTL has controlled or even dominated the scene; actually, it is one of perhaps two dozen organizations that have consistently backed the meeting over the years.

It has been said that CEDR is the conference to which other laboratories send people to find out what is going on at BTL. Bell engineers modestly retort that it is, on the contrary, the conference to which BTL sends a platoon to find out what is going on at other laboratories. Participants listening to one Bell engineer questioning another after his paper has been presented have sometimes wondered if this was not the conference to which giant BTL sent its engineers to find out what was going on at BTL.

REFERENCES

1. Price, D. J. de S., *Science Since Babylon.* New Haven, Conn.: Yale University Press, 1961.
2. *Proc. IRE*, vol. 27, pp. 74, 153, 228, 616, 1939.
3. Kompfner, R., *The Invention of the Traveling-Wave Tube.* San Francisco: San Francisco Press, 1964.
4. Profile in *The New Yorker*, Sept. 21, 1963.

Technical correspondence

Prior art of electron devices

I am sure that many of us who have been working in the field of electronics and solid-state electronics for many decades read Dr. Kompfner's comprehensive essay, "Electron Devices in Science and Technology," (IEEE SPECTRUM, pp. 47–52, September 1967) with great interest. Dr. Kompfner gives deserved credit to inventors in a fair manner. However, when reading his article I thought that, for the benefit of members of the younger generation, who are generally unaware of the prior art of certain inventions, it would be beneficial to call attention to certain inventors and contributors, some of whom may deserve the Nobel Prize candidacy. I would like to enumerate some prior art and the scientists who were contributors and fellow workers and who, in my modest opinion, certainly deserve credit.

Photomultipliers

The story of the invention of photomultipliers is not so simple. It started with Philo T. Farnsworth, who, in the opinion of many people, including myself, is one of the most brilliant geniuses of the United States. He was practically a teen-ager when he invented the image dissector tube[1] (which, incidentally, is again being used—in space vehicles to track the stars the vehicle locks on). At the time of its invention, it was to be used as a television pickup tube. The picture to be televised was projected on a transparent photocathode. However, the number of photoelectrons emitted by one picture element was very small. Therefore, the young Farnsworth invented, independently, an electron multiplier to multiply the photo-emitted electrons in his device. At that time, electron multipliers were known to some people in the field. The thermionically emitted electron multiplier—essentially a secondary electron multiplier—was invented by Slepian in 1919.[2] The technique of secondary electron multiplication was further developed by Ruben[3] in 1920, by Thomas[4] in 1923, and by Jarvis and Blair[5] in 1926. In 1935–1936 G. Weiss published a description of an interesting photomultiplier tube.[6,7]

In 1935 I happened to be in Farnsworth's laboratory and the two of us discussed the operation of the multiplier part of the image dissector. But, not knowing the prior art of the multiplier, it was difficult at that time to give the right answer (that was 32 years ago); however, the multiplier worked.

From the secondary electron multiplier to the photomultiplier, as we know the device today, was indeed a step forward. Whether or not this step was obvious to the people who became knowledgeable in the prior art is a matter for discussion, as far as the criterion of a patentable invention is concerned, but the step was important.

The tunnel diode

Around 1925 an interesting point contact detector was published by Lossev in the radio circuit literature (which included a Hugo Gernsbach publication) in the United States. This detector showed a negative impedance characteristic and was capable of doing many of the tricks a tunnel diode could do. It was, at that time, used primarily to make a diode oscillator or to reduce the Q value—the figure of merit—of a resonant circuit. Of course, many decades passed before the important tunnel diode was invented, but it is, nevertheless, worth mentioning because the junction transistor also came from the point contact transistor.

The optical maser

In 1955 the maser was announced.[5] C. H. Townes had worked on this with his very capable students during the previous year. J. P. Gordon and H. J. Zeiger were certainly present at the birth of the laser (optical maser), their contributions being indicated by the fact that both are coauthors of the maser paper,[8] which otherwise would not have been the case. Shockley, Bardeen, and Brattain worked together too. I believe it is in order here to mention Gordon Gould, who, when working at Columbia University in 1957, made contributions to what is now called laser technology. Townes filed for a U.S. patent on the production of electromagnetic energy, which is a maser patent, on January 28, 1958, and it was issued to him on March 24, 1959, as no. 2 879 439. A. L. Schawlow and C. H. Townes made important contributions to lasers in the paper they published in 1958.[9] But Schawlow emphasized the difficulties in producing stimulated emission with ruby on the R_1 line.[10]

T. Maiman succeeded in building the ruby laser, and great credit is due to him. This is just as important as the invention of the arc transmitter by Waldemar Poulsen, who actually built the first continuous-wave transmitter. Prior to his invention, many people anticipated this transmitter, and after its invention, that of radio telephony.

Holography

With the invention of holography, D. Gabor[11,12] started a far-reaching technology of tremendous importance. However, the work and contributions of Leith and Upatnieks[13-15] should not be forgotten. They were the first to make a slide picture, and a three-dimensional picture hologram, a true accomplishment.

The traveling-wave tube

As is well known, Dr. Rudolf Kompfner is the inventor of the traveling-wave tube. When I taught this extraordinary discovery, which is a milestone in the field, to my students, I told them that we electrical engineers—Kompfner's contemporaries—ought to be ashamed of ourselves that we had not invented this tube. Kompfner started his career not as an engineer but as a graduate architect. This shows his greatness.

I urge readers who are interested in the way in which inventions are born to read Kompfner's book.[16] Dr. Pierce wrote the foreword, mentioning that he saw Kompfner in England in 1944 just after the latter had invented the traveling-wave tube. (See Kompfner's Notebook entries in this book, dated Sept. 6, 1942, Nov. 10, 1942, Nov. 12, 1942, and Nov. 13, 1942, and you will agree with me as to the extraordinary value of this creative genius.)

"Life is unfair," one of our great Presidents said not long ago. Sometimes, life is unfair to the inventor too.

Victor A. Babits
Palos Verdes Peninsula, Calif.

REFERENCES

1. Farnsworth, P. T., "Television by image scanning," *J. Franklin Inst.*, vol. 218, no. 4, p. 411, 1934; U.S. Patent no. 1 773 980, 1931.
2. U.S. Patent no. 1 450 265.
3. U.S. Patent no. 1 559 460.
4. U.S. Patent no. 1 704 155.
5. U.S. Patent no. 1 903 569.
6. Weiss, G., *Fernsehen*, vol. 6, p. 55, 1935; vol. 7, p. 41, 1936.

Book reviews

Physics and Technology of Semiconductor Devices, A. S. Grove—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y., 1967; 355 pages, illus., $12.95.* A more descriptive title for this book would be "Technology of Silicon Planar Devices." From the vast number of topics in the field of semiconductor technology, the author has chosen to emphasize those associated with silicon wafer preparation and surface phenomena, both of which are of major importance to the fabrication of silicon planar devices.

The book begins with a section that covers three aspects of silicon wafer preparation: vapor-phase epitaxial growth, thermal oxidation, and solid-state diffusion. Each aspect is highlighted by a detailed study of a widely used system, which is compared with a simplified mathematical model. The discussion is concerned mainly with principles rather than the practical aspects of carrying out the various processes.

The final section is a clear account of phenomena associated with thermally oxidized silicon surfaces. The discussion is based principally on the published work of the author and his co-workers and represents an excellent summary of such phenomena on an introductory level. Again, the emphasis is on principles and models rather than on the techniques for achieving a desired structure or characteristic. Surface effects associated with both p-n junction and metal-oxide-semiconductor devices are considered.

The book is diluted by a section on the physics of semiconductors, which, although it occupies nearly half of the volume, adds very little to the existing literature. The emphasis is on p-n junctions and junction devices at a very elementary level. Although the desirability of a self-contained treatment may be a strong argument for the inclusion of this material, its usefulness is severely restricted both by placement and by lack of rigor in the development. In particular, the limitations inherent in the various approximations used are rarely pointed out.

Numerous problems are provided at the end of each of the 12 chapters. In many cases these carry the reader beyond the discussion in the text. General as well as specific references are cited wherever they exist. The subject index is ample, but no author index is included. The book is profusely illustrated, but all too frequently the publisher has placed the illustrations inconveniently with respect to the text material. The comprehensive list of symbols at the beginning of the book is very helpful to the reader.

The level and scope of the book make it most suitable for students being guided by an experienced instructor. It is more suitable for experienced practicing engineers who wish to expand their knowledge into the specific areas of technology covered in detail than for those who need a basic reference in semiconductor physics. Both the discussion of wafer preparation and surface phenomena are unique and worthwhile contributions to the literature. Perhaps in future editions the author will consider the advisibility of expanding these sections and relying on other of the numerous satisfactory books on the physics of semiconductors for the necessary background material. Such a volume, devoted entirely to the technology of silicon planar devices, would fill a real void.

W. Murray Bullis
National Bureau of Standards
Washington, D.C.

Introduction to Radio Astronomy, R. C. Jennison—*Philosophical Library, 15 East 40 St., New York, N.Y., 1967; 1954 pages, illus., $4.75 pprbk.* Written to "bridge the gap between the textbook and the too-popular treatment of an exciting and rapidly advancing science," Professor Jennison's book touches on all fields of astronomy that have been contributed to by radio methods.

A description of the quiet sun, as it reveals itself by its radio emission from decameter wavelengths to microwaves, is followed by mention of the slowly varying component and the various types of bursts emitted by the active sun.

A discussion of lunar radiation, and its possibilities for subsurface mapping, leads to consideration of radar techniques for mapping the moon and planets. Radar has been remarkably successful in improving the accuracy of interplanetary distances, revealing the rotation of planetary surfaces concealed by cloud, and in providing high-resolution maps of optical quality or better.

The story of radio stars is told with historical detail; in fact, the whole book has a historical slant, with emphasis on the view of radio astronomy as seen from Jodrell Bank, where the author's original researches were carried out. Some appreciation of the excitement over the race to measure the angular diameter of Cygnus A is conveyed, and we learn how this led to the discovery of the double nature of many radio sources.

Observations made by means of the hydrogen line at 1420 MHz are discussed; as time goes on, radio-frequency spectroscopy will continue to develop as a consequence of the discovery of the lines of OH, excited hydrogen, and other atoms and molecules.

In addition to its astronomical content, the book contains chapters on techniques, types of radio telescopes, and an appendix on the Fourier transform.

R. N. Bracewell
Stanford University
Stanford, Calif.

Signal Detection Theory and Psychophysics, David M. Green and John A. Swets—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y., 1966; 346 pages, illus., $12.95.* In recent years there has been a surge of interest in developing engineering specifications for that illusive system component, man. The motivation for this interest stems from the desire to develop analytical techniques for the design of man–machine systems. Perhaps the most successful attempts to provide such an engineering description have arisen from the application of the subset of statistical decision theory, called detection theory, to the specification of human sensory or perceptual capacities. In the brief span of 13 years since the appearance of the Tanner and Swets pioneering article,[1] more than 100 papers have been published that focus on psychophysical applications of detection theory. Today, the serious student of human sensory or perceptual sensitivity is severely hampered without at least a conceptual understanding of receiver operating characteristics, the ideal observer, and d', the detection theory measure of sensitivity. The most significant contribution of detection theory concepts is a measure of receiver detection sensitivity that is independent of the biases in the observer's subjective criterion for saying whether a signal was present or absent.

Before the appearance of this book and its companion volume,[2] the student, research worker, or design engineer who wished to understand the theory, employ the paradigms, or apply the results needed to devote a significant effort to filtering through the myriad of research papers. Now, thanks to the diligent and thorough efforts of authors Green and Swets, the significant theoretical and empirical results have been collected in a single volume, and have been woven into a coherent text that focuses on issues and on the strengths and weaknesses of available data for resolving those issues.

The book is divided into three sections. Part I is devoted primarily to the role of decision processes in detection. It presents the elements of statistical decision theory, and develops the experimental procedures that yield independent measures of the observer's decision criterion and his sensitivity. Part II emphasizes the direct contribution of the theory to the understanding of sensory processes in detection. One might criticize Parts I and II for their emphasis on auditory detection data to the virtual exclusion of empirical work on other senses, save a sprinkling of visual detection experiments. However, this is more a criticism of the research that has been undertaken than it is of the book itself, since it is a practical fact that it is in the auditory domain that most of the work has been done. After all, it has been only 13 years.

In the remaining chapters of Part III, a much broader range of applications of detection theory to problems in psychology is discussed. But, again, reflecting the state of the research accomplished to date, these chapters are more superficial than those of Part I or II.

The inclusion of three appendixes, elements of probability theory, basic concepts of waveform analysis, and experimental techniques, is intended to make the book complete without extensive prerequisites. However, the reader without substantial mathematical sophistication will find that he must leave most of the theoretical derivations behind and concentrate on concepts and data. Nevertheless, the serious student who works through the book in its full depth will pay tribute to the thoroughness of the authors and rebuke them for occasional typographical errors, and return to their work with a state-of-the-art understanding of signal detection theory and its application to human sensory system performance measurement. From that vantage point it is only a small step to engineering applications of detection theory in man–machine systems.

Richard W. Pew
University of Michigan
Ann Arbor, Mich.

---

1. Tanner, W. P., and Swets, J. A., "The human use of information: I. Signal detection for the case of the signal known exactly," *IRE Trans. Information Theory*, vol. PGIT-4, pp. 213–221, 1954.
2. Swets, J. A., *Signal Detection and Recognition by Human Observers: Contemporary Readings (Ed.).* New York: Wiley, 1964.

Communication Satellite Systems Technology, Richard B. Marsten, ed.—*Academic Press Inc., 111 Fifth Ave., New York, N.Y., 1966; 1051 pages, illus., $12.00.* This book is a compilation of papers presented at the 1966 Communications Satellite Systems Conference of the AIAA. The papers have been carefully selected and grouped to provide a comprehensive treatment of satellite communications systems, both commercial and military. The book begins with Arthur C. Clarke's 1945 *Wireless World* paper entitled "Extra Terrestrial Relays." This prediction of worldwide radio coverage by satellites using solar power and approximately 1-kW power levels, atomic fuels, and multistage rockets is a valuable inclusion, and it may serve to inspire more of the responsible long-range thinking required for this field to continue its rate of growth.

A strong emphasis is placed on systems problems, with two sections (Support Subsystems and Components and High-Power Systems) dealing with such techniques areas as antennas, stabilization, and TWTs. Like most collections of papers, the level and quality of the treatment vary somewhat, but all of those areas with which the reviewer is conversant have been dealt with respectably.

One of the authors (Charles M. Kelly) makes a strong case for continuing passive satellite development, and one of the papers (by Chapoton and White) examines optical communication possibilities in a very comprehensive fashion. The differing points of view of the Comsat Corporation and AT&T as to the relative merits of Early Bird and Cable Circuits are clearly visible in the two papers by Barstow (Comsat) and Helder (BTL). I found these two treatments of subjective evaluations made by users very encouraging and illuminating.

The "Sociological Overview" at the end of the book obviously suffers from being restricted to papers that were presented at this conference. "Sociological" just means, in this instance, nontechnical. The significant sociological implications of routine intercontinental transmissions of news, sports, cultural programs, and inexpensive telephony were hardly touched. These political and sociological factors may well serve as the only limit, or the most important motivation to communication satellite development.

The experience of the military in operating pilot Satcom systems is encouragingly reported in a paper by W. H. Edwards and J. S. Smith. It appears that both commercial and military experience with synchronous altitude-length delays has been much less troublesome than was expected only a very few years ago.

This reviewer has always felt, privately, that communication satellite systems could become the best proving ground for some of the new systems disciplines. In particular, that much abused specialty, cost effectiveness, should, if it offers anything, be able to help guide our efforts in this area, in which we have such a plethora of cost data and reliability measures. In "Cost Effectiveness Comparison of Defense Communications Satellite Systems" by Guggenheim, Gernholy, and Collins, the reviewer found a considered, comprehensive, and realistic evaluation of systems by cost-effectiveness criteria. This treatment has served to moderate the suspicion with which I have always approached articles in this field. I believe this paper would prove to be useful reading to all those who hold systems responsibility in communications.

This book is well worth having in the libraries of communications systems engineers and those of their managers.

James Litton, Jr.
Magnavox Research Laboratories
Torrance, Calif.

Introductory Signals and Circuits, Jose B. Cruz, Jr., and M. E. Van Valkenburg—*Blaisdell Publishing Co., 275 Wyman St., Waltham, Mass.; 430 pages, illus., $10.50.* One of the basic problems with teaching circuits at the sophomore level is the problem of motivating the students while avoiding oversimplifications that lead to a misconception. This new book by two well-known circuit theorists and educators is a welcome addition to the textbook field because it makes a concerted attack on the problem. The primary engineering applications of circuits are in signal processing. Most beginning circuits texts do not give the student sufficient background in signals to motivate him. This text does. In fact, the first 62 pages deal primarily with signals, with little said about circuits.

When circuits are introduced, the authors include controlled sources, gyrators, and other non-*RLC* elements. Thus, the student is prepared, at least somewhat, for the modern engineering world of integrated circuits where active and passive components are all handled by the same techniques. In addition to the electrical elements, mechanical elements are presented in the network models chapter.

The treatment of Kirchoff's laws, Thévenin's theorem, and other such topics is not too different from that of competing circuits books. In the chapter on equilibrium equations, the authors have included the formulation in terms of state variables. The chapters on sinusoidal steady-state analysis, network transfer functions, and filtering are also fairly conventional. The one addition that is not emphasized in most other circuits books at this level is the introduction of energy and power concepts. The terms passive, active, and lossless are all defined.

This reviewer is very pleased that the authors completely avoid Laplace transforms in their discussion of the general response of circuits to arbitrary signals. They introduce convolutions in one chapter, and in the final chapter they discuss the classical solution of homogeneous differential equations. Unfortunately, these two chapters are not tied together well, and the student will probably get little connection between forced and natural response from the text. Of course, the book is not intended for self-study and, presumably, any reasonably skilled professor can make the connection for the student.

This reviewer's objections to the book are comparatively moderate and, with skilled instruction, can probably be completely eliminated in a course with this text. Although controlled sources are introduced early, almost all the examples and most of the homework problems are still *RLC*. The background is there for work with linear electronic circuits. The professor will have to make his own examples and homework for the students. The impulse, as in most elementary circuits texts, is introduced as a limit that doesn't exist. The authors have modified the traditional demonstration of the application of impulse response and improved things slightly. Nevertheless, they still must use a nonexistent limit to show the final convolution form. A better derivation of the forced response is certainly in order and within the grasp of students of this level.

In summary, this reviewer believes that if first-semester sophomores are to be started on a course in circuit theory, this book is the best on the market. If the circuit theory is to wait until the second course, then the treatment herein is too elementary. The authors state in their preface that the book can be covered in about 70 class hours at the sophomore level. This reviewer, who has considerable experience in instructing sophomores in circuits theory, believes that the material can be covered in even less time if the circuits course is accompanied by a good laboratory. The authors claim that at the junior level progress could be even faster. This reviewer would recommend using a different book for juniors.

A final strong point of the book is the symbols used for current and voltage sources. These symbols were agreed upon by a group of circuit theorists, including the authors and this reviewer, at the fourth Allerton Conference on Circuit and System Theory. The present book is the first in which the symbols appear.

B. J. Leon
Purdue University
Lafayette, Ind.

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.

Chemical Bonds in Semiconductors and Solids, N. N. Sirota, ed.—*Consultants Bureau, Inc., 227 West 17 St., New York N.Y., 1967; 293 pages, $27.50.* In recent years, the broadening field of application of semiconductors, the increasing understanding of their physical and physicochemical nature, and the attention given to a number of classes of semiconducting compounds have raised the question of the nature of the chemical bond in semiconductors. The problem of chemical bond takes on special significance in the field of quantum electronics. This book presents the results of a large number of theoretical and experimental investigations, the included papers being grouped under the following headings: general questions relating to the chemical bond in semiconducting crystals; experimental determination of electron density and evaluation of the chemical bond in semiconductors; thermochemical data characterizing the energy of the interatomic bond; dynamics of the crystal lattice of semiconductors and the chemical bond in crystals; and questions of the chemical bond and the physical properties of semiconductors.

Computer Technology (*IEE Conference Publication no. 32*), *Institution of Electrical Engineers, Savoy Place, London W.C.2, England, 1967; 237 pages, pprbk.* This volume contains the papers presented at the Conference on Computer Technology, which was held in July 1967 in Manchester, England. The papers are grouped under the following headings: automatic methods; storage; central processor techniques; semiconductor devices; transmission line circuit techniques; communications; and displays. Among the topics included are procedures for the placement and interconnection of integrated circuits in digital systems, small-capacity thin cylindrical magnetic film storage systems, a time-sharing system using an associative memory, and the use of field effect transistors in parallel binary adders.

Electrical Characteristics of Transistors, R. L. Pritchard—*McGraw-Hill Book Co., 330 West 42 St., New York, N.Y., 1967; 715 pages, $19.50.* In this book the author attempts to fill the void between existing texts on semiconductor physics and texts on transistor circuit applications, which generally include only one or two chapters on electrical characteristics of transistors. It is not possible in such texts to describe electrical characteristics in detail. In this volume, the fundamental properties of the transistor are reviewed and expanded upon, and the difference between practical transistor structures and the usual simplified models are described in considerable detail. Topics covered include dc characteristics, low- and high-frequency ac characteristics, equivalent circuits,