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IEEE spectrum

features

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THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

departments

the cover

One problem for a geologist is to determine whether or not a pattern of rock fractures, such as those traced from an aerial photograph (see cover), have a preferred orientation. Optical transformation techniques, discussed in the article beginning on page 59, may make obvious the answers to this and many other similar scientific problems.

The application of digital frequency synthesis techniques at RF frequencies has been utilized in the design of an L-Band Frequency Synthesizer. Carl Schleicher, a Group Leader in the Reconnaissance Systems Department, comments on some important characteristics of the unit.

L-Band Frequency Synthesizer

AIL has been active for a number of years in the development of frequency synthesizers to provide precise, agile signal sources for receiver and transmitter applications. We have recently completed the development of an L-band synthesizer which required high reliability, minimum size and weight, and 60 db spurious rejection. In addition, more than 1000 discrete frequencies were required with an accuracy and resetability of one part in 10^6.

Conventional techniques using VHF and UHF multiplier chains, switches, and filters in either direct (no phase-lock loops) or indirect (phase-lock loops) synthesis were ruled out for this application due to the size and weight of the filters and other subassemblies required for adequate spurious suppression. A frequency settling time requirement of one millisecond maximum allowed use of a relatively narrow bandwidth digital synthesizer technique with the advantages of ease of spurious suppression, minimum weight, and high reliability. Note that digital synthesizers can operate at faster switching speeds at the expense of additional complexity which was not needed in this application.

The digital frequency synthesizer technique (Figure 1) is basically a narrow bandwidth phase-lock loop (PLL) which uses a single, stable, reference frequency and indirect frequency synthesis. Operation of this synthesizer is amply described in the literature. The greatest advantages of the digital synthesis technique are small size and weight and high reliability since integrated circuits can be used almost exclusively. The size advantage of the digital synthesizer is a direct function of the number of frequencies to be synthesized and is not usually worthwhile unless 500 to 1000 frequencies are to be generated. Note that the larger the number of frequencies required in a given frequency range, the smaller the value of f_{REF} and, consequently, the larger the frequency settling time (t_s) assuming all other variables constant. Both fast switching and small steps (ΔF) can be accomplished by an additional loop(s).

Frequency of operation is limited by the prescaler (500 MHz maximum with unsaturated logic), the variable digital divider* (20 MHz with TTL saturated logic), and the binary scaling factor L.

The L-band frequency synthesizer (Figure 2) can be considered to combine both analog and digital indirect synthesis. Analog synthesis is utilized to subdivide the output frequency range into X frequency ranges and is accomplished by down-converting the output frequency (f_o) to an IF frequency by means of a balanced mixer and a variable reference signal (f_s). A harmonic multiplier chain, in conjunction with a varactor-tuned cavity resonator, generates the reference signal (f_s). Logic controlled by the binary frequency word programs the tuning voltage to the varactor circuit which determines the harmonic of 128 MHz selected as the f_s signal. Each subdivided VCO output frequency range utilizes the same IF frequency range. Operation of the PLL is similar to that of the digital synthesizer mentioned above with the exception of the additional frequency translation in the balanced mixer.

Possible spurious outputs in the L-band synthesizer can be divided into two convenient categories—those resulting from undesired FM of the VCO and those resulting from insufficient isolation in the RF signal path (spurious outputs resulting from radiation, poor grounds, etc., are not considered since good RF practice lowers spurious outputs of this type to well below the required 60 db down). The only spurious outputs of the RF signal path type are f_s signals which are a function of the f_s power level, isolation of the balanced mixer and are well below 60 db down. FM was limited to less than 10 kc peak-to-peak on this particular synthesizer and required attenuation to phase detector ripple outputs and noise outputs from amplifier stages used to generate the VCO tuning voltage. Varactor tuned transistor oscillators at L-band have a df/dV of 50 MHz per volt at the low end of the band which required tuning voltage spurious levels less than 200 microvolts peak-to-peak to meet the FM noise requirement.

The digital synthesis technique was used to solve a particular L-band signal source problem and is not the optimum approach to all synthesizer requirements. This does illustrate a different approach to microwave synthesizers where most of the circuitry required is low frequency analog or digital circuits which can utilize off-the-shelf monolithic integrated circuits on plug-in multilayer PC boards for high reliability and small size.

The complete package for the synthesizer, less isolator regulators, is shown in Figure 3. Approximate size, weight, and DC power are 280 cubic inches, 7 pounds, and 25 watts, respectively.

If more information is desired on this subject, the author will be glad to supply it.

*"High Speed Binary Division," IEEE Spectrum, 1966.

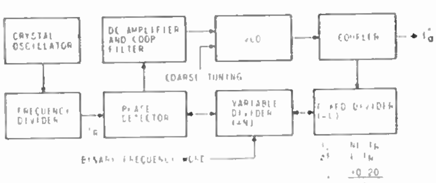

Figure 1. Digital Frequency Synthesizer

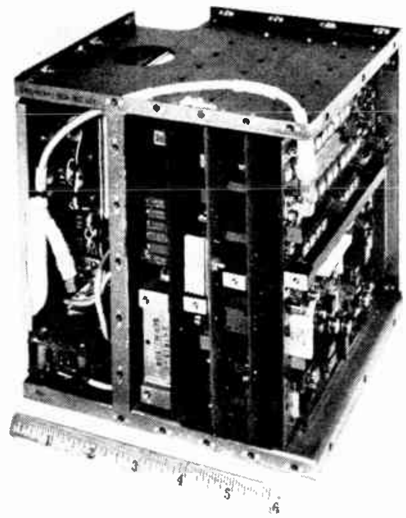

Figure 3. Frequency Synthesizer Package

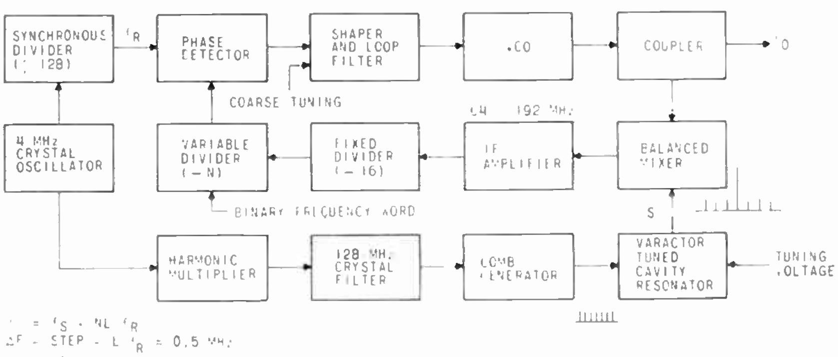

Figure 2. L-Band Frequency Synthesizer

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IEEE spectrum

Spectral lines

The future of Europe. This column last month was to have been devoted to a consideration of the technology gap as viewed through the eyes of J.-J. Servan-Schreiber and delineated in his much-noticed book, *Le Défi Americain* ("The American Challenge").[1] The deadline for the August issue arrived before the book did, so the editorial consisted of some thoughts of my own that were generated by musing on the same topic. Since then, a summary in *Harper's Magazine*[2] has made the main outline of Servan-Schreiber's thesis available to people who read English but not French. However, much that should be of interest to engineers does not appear in the *Harper's* condensation. In particular, there is no hint there of the importance that Servan-Schreiber attaches to electronics, and especially to computers.

The theme of the book is the expansion of American economic power in Europe, not so much by a transfusion of capital as by a seizure of power—a takeover based on superior management.

American penetration, says the author, selects areas notable for technological sophistication, rapid innovation, and a fast rate of growth. One such area is electronics. The figures given for the fraction of European electronics production controlled by American firms are: consumer goods (e.g., radio and television receivers), 15 percent; semiconductors, 50 percent; large electronic computers, 80 percent; integrated circuits, 95 percent. The author finds these figures threatening because the second industrial revolution—now in progress—rests on the electronic devices that take over, each year, an increasing number of the tasks recently performed by human brains. He says that a country which has to buy its electronics from foreigners will be in the same position as the nations that, a century ago, failed to master the design and production of mechanical devices; if Europe fails to remain at the forefront of electronics, Europe in the very next generation may have ceased to possess an advanced culture. To justify this extreme statement, he makes the assumption (which seems to me quite undependable) that American companies that have acquired huge markets and high profitability in Europe will nevertheless, in their policy decisions, be influenced only by their capital and sales positions in the U.S. He is led to the conclusion that Europe will take on the status of a satellite.

He paints a bleak picture. Accepting American firms dooms European ones—at least those most technologically oriented, on which the future depends—to subsidiary roles. Restrictive measures, on the other hand, will, if effective, deprive Europe of products that it needs, and of capital that will go elsewhere. Nationalization of American holdings he condemns as a soothing substitute for thought; nationalization looks like a way of handling the future, but it turns out to be merely a way of arresting a country's growth.

One might suppose that the American penetration of European industry has been made possible by an unmatchable inflow of capital. Apparently not. In 1965, American investment in Europe amounted to four billion dollars, but only about ten percent came from the U.S.; 90 percent was found in Europe itself. Servan-Schreiber warns, "With our own money, they are buying us."

He believes that the American challenge arises not so much from wealth or engineering competence as from managerial skill. In particular, Americans have appreciated the significance of the Common Market, and are operating in it while the Europeans are still trying to learn how.

He offers a prescription for the future. In sum, it is to contrive a polity that is European, rather than national, in its economics. He wants systematic strengthening of industrial enterprises that prove themselves adept at meeting the American challenge, so that they will grow large. To generate innovation, he wants the supranational federation to let contracts to industry, as the U.S. Government does. He wants deeper and more general education for the young, and a revolution in the techniques of management.

For many readers of IEEE SPECTRUM, the most interesting aspect of the author's thesis is that the next phase of Western culture is being shaped by their daily work. The book does not ring with quite the authority of the Ten Commandments, but it is thoughtful and lucid; it will undoubtedly have great influence.

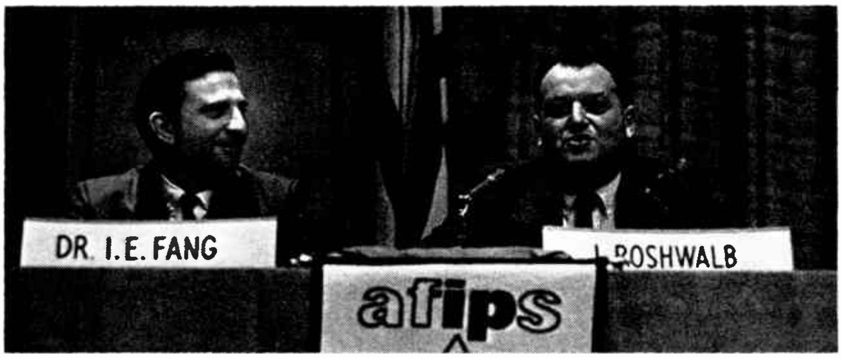
J. J. G. McCue

1. Servan-Schreiber, J.-J., *Le Défi Americain*. Paris: Editions Denöel, 1967.
2. Servan-Schreiber, J.-J., "The American challenge," *Harper's Mag.*, vol. 237, pp. 33–42, July 1968.

Editor's note: Since the above lines went to the printer, an English translation of the Servan-Schreiber book has been issued by Atheneum Publishers, New York, N.Y., under the same title as the article in *Harper's*.

Authors

Election projection seminar (page 40)



Irving E. Fang is assistant manager of the ABC News Political Unit, which has overall charge of the network's vote-gathering and analysis operation for primary and general elections. He has been a journalist since 1951 and with ABC News since 1960. He holds the B.A. degree in English and the M.S. degree in journalism. He received the Ph.D. degree in speech from U.C.L.A. in 1966. He has published several articles on computer-derived language analysis. He is also the author of a textbook, *Television News*, scheduled for publication this summer. **Irving Roshwalb** is senior vice president of Audits & Surveys, Inc. He is also currently teaching statistics on the graduate faculty of the City University of New York. Mr. Roshwalb holds a master's degree from Columbia University and a B.S. degree from the City College of New York. He has written on sampling, mathematical models for measuring attitudes, and panel analysis for publication in various professional journals. He is a member of the American Marketing Association, the American Statistical Association, the Institute of Mathematical Statistics, and the American Association for Public Opinion Research. He was formerly chief statistician for the Opinion Research Corporation. **Jack Moshman** is vice president of Leasco Systems & Research Corporation. He was formerly managing director, management sciences, with EBS Management Consultants, Inc., and vice president and general manager of the Applied Research and Management Sciences Division of C-E-I-R Inc. He received the Ph.D. degree in mathematics from the University of Tennessee in 1953. Previous affiliations include Bell Telephone Laboratories and the U.S. Atomic Energy Commission. **Donald G. Herzberg** is executive director of the Eagleton Institute of Politics, Rutgers University and is also a professor of political science. He formerly held positions with Chatham College, Wesleyan University, the Maxwell School, and Syracuse University. He received the B.A. degree from Wesleyan in 1946 and pursued graduate studies at Syracuse. He has served as editor on several editions of the *American Government Manual*, and has been author or coauthor of a number of books on politics.

To understand brains (page 52)

Nilo Lindgren received the B.S. degree in electrical engineering (communications) from M.I.T. in 1948, and also studied art, literature, and psychology at various schools, including the Tyler School of Fine Arts, University of Pennsylvania, and Harvard. He was a technical writer and editor in the research departments of Philco, Hughes Aircraft, and Grumman Aircraft. As an editor on *Electronics*, McGraw-Hill, he wrote many articles, including surveys on microminiaturization and bionics. He has also written for industrial films, was a McGraw-Hill correspondent in Finland, and wrote travel articles for *The New York Times* and *Travel Magazine*. In the past four years, he has written for IEEE SPECTRUM broad reviews of research on machine recognition of human language, human factors, artificial organs, electric cars, speech research, cybernetics, and biomedical engineering.

Optical processing in the earth sciences (page 59)

M. B. Dobrin is vice president and chief geophysicist of the United Geophysical Corporation, a subsidiary of the Bendix Corporation, which is primarily engaged in petroleum exploration under contract to oil companies. He received the Ph.D. degree in geophysics from Columbia University in 1950. He has been engaged in geophysical work since 1937, when he joined Gulf Research & Development Company. Dr. Dobrin has been with the United Geophysical Corporation since 1961. His primary research activity there has been in the development of optical techniques for the analysis and filtering of seismic data. He is one of the inventors of a process for enhancing seismic information by this approach. He has also worked on the processing of geological information by optical means. He is the author of *Introduction to Geophysical Prospecting*, published by McGraw-Hill in 1960.

Planning for power—a look at tomorrow's station sizes (page 67)

R. R. Bennett, a consulting mechanical engineer for Ebasco Services Inc., is responsible for overall technical supervision and consultation on all mechanical engineering matters pertaining to domestic and foreign steam-electric stations, as well as consultation to utilities and industries on fuel availability and pricing, site selection, unit sizing, thermal cycles, and the economics of power generation. Since joining Ebasco 24 years ago he has served as project engineer for approximately 40 steam-electric stations. Mr. Bennett attended the Polytechnic Institute of Brooklyn, from which he received the degree of bachelor of mechanical engineering in 1935. Since that time he has also taken a number of graduate courses at Columbia University, chiefly in the field of nuclear engineering.

Nuclear test instrumentation with miniature superconductive cables (page 91)

D. K. Rathbun (M) received the B.S.E.E. degree from the University of Southern California in 1960 and the M.S.E.E. degree from Catholic University in 1965. He was on active duty in the U.S. Navy from 1960 to 1965. From 1962 to 1965 he was on the faculty of the Science Department, U.S. Naval Academy, where he taught several undergraduate courses in electrical engineering. In 1965 he joined Sandia Corporation, where he has been working on the development of instrumentation systems. Present projects include a single transient analyzer utilizing pulse storage on a superconducting coaxial cable. **H. J. Jensen** (M) is a professor of electrical engineering at the University of California, Davis. He received the B.S. degree from Oregon State University in 1959, the M.S. degree in 1965 from U.C.D., and will soon receive the Ph.D. degree. From 1959 to 1965, as an electrical engineer at Sandia's Livermore Laboratory, he did R & D work in transient measurements, data processing, and semiconductor particle detectors. From 1965 until his recent faculty appointment he was a Teaching Fellow at U.C.D.

TVA—Nondomestic purchases by a government utility (page 100)

Raymond L. Forshay received the B.S. degree in civil engineering from the University of Tennessee in 1944. He had begun his engineering career with the Nebraska State Department of Roads and Irrigation before joining the Tennessee Valley Authority in 1936. After doing engineering work in the development of Tennessee River multipurpose hydro projects and steam-electric generating stations he moved to Chattanooga to work with the TVA's Office of Power in power marketing, personnel administration, and general management. He became director of purchasing for TVA in 1965. He has been active in professional engineering circles, serving as president of the Tennessee Valley Section of the American Society of Civil Engineers and on national ASCE committees. He is a Fellow of the ASCE, a member of Tau Beta Pi, and a licensed professional engineer in the State of Tennessee.

Election projection seminar

Irving E. Fang ABC News
Irving Roshwalb Audits & Surveys, Inc.
Jack Moshman Leasco Systems & Research Corporation
Donald G. Herzberg Rutgers University

From April 30 to May 2 of this year, the 1968 Spring Joint Computer Conference, sponsored by the IEEE Computer Group and the American Federation of Information Processing Societies (AFIPS), presented 21 technical sessions designed to provide a broad view of the latest developments in computer hardware, software, and applications. Included in the Atlantic City, N.J., meeting was a special panel, chaired by Dr. I. E. Fang, formed to discuss the advances made by the computing, communications, and broadcasting industries that have made it possible to predict the outcome of elections, based in part on returns from a limited number of preselected areas. The four presentations of this session are given here, and include, as an illustration, an overview of the design and operation of the election reporting system now being used by the American Broadcasting Company in this critical election year.

The flow of information through a broadcast network on election night: the ABC system

Irving E. Fang

Most information on election night is numeric. We get it everywhere in the U.S. as fast as we can lay our hands on it; we transmit it as accurately as human beings and machines can manage; we organize it and analyze it to make as much sense out of it—to garner as much meaning from it—as can be determined by the most politically knowledgeable men we can find; then we deliver it to millions upon millions of people as clearly, as instructively, as interestingly as we know how. That's why millions upon millions of people watch network programs on election night. In 1964, an estimated total of 95 million people watched television alone. Other millions listened to radio.

On the night of a presidential election, such as we will see on November 5, history unfolds. We at the networks know it. Those at home know it. This sense of communicating history, this sense of communicating what political life may be for us all in the years ahead, is perhaps the main reason so much effort and so much energy is poured into this public service broadcast by the television networks.

We at the American Broadcasting Company (ABC) get information on election night from four sources. We deal with it seven ways at five desks, and transmit it by three methods to everyone's home. This is our input, internal handling, and output—our throughput.

We'll start with the News Election Service (NES). It was formed by ABC, the National Broadcasting Company (NBC), and the Columbia Broadcasting System (CBS) in time for the Johnson-Goldwater election as a pool organization to report the total vote in each state—which we call raw vote, to distinguish it from key-precinct vote. The Associated Press (AP) and United Press International (UPI) joined soon after. These five great newsgathering organizations share in the task of getting the raw vote—the totals you will see on the tally boards behind Howard K. Smith, Walter Cronkite, and Huntley and Brinkley. There will be no point in flipping the dial to see who is ahead. All stations get the same figures at the same time.

It is the intention of NES to put a reporter into most of the precincts of the United States—perhaps 70 percent of them. The reporters will not be journalists, but responsible citizens: school teachers, Jaycees, and so forth. We are talking about 120 000 reporters. And, as backup, a reporter will be in every county of the United States, and so, hopefully, every vote counted through the long election night will be reported that night.

In 1968, for the first time, an NES computer system

A discussion on the use of computer, communication, and broadcasting technology in processing election returns

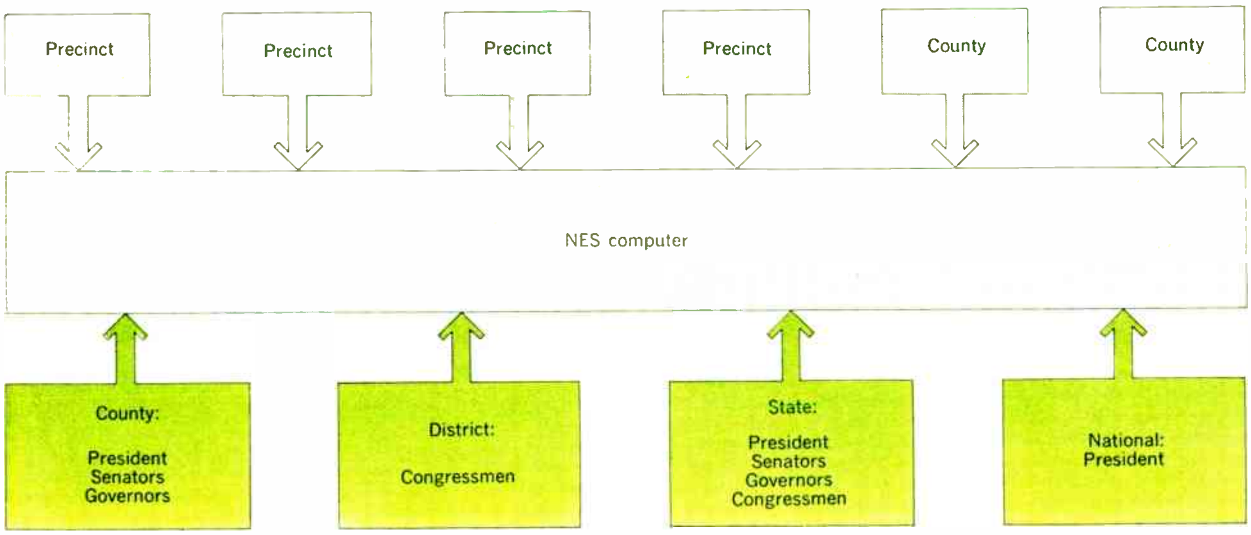
For the first time in election history, the task of tabulating early "raw" and key-precinct returns for the entire U.S. will be completely computerized, enabling the major networks to convert the data into more reliable predictions sooner

will be in operation for the entire U.S., a system which was successfully tried in the 1966 elections for the 11 western states. In the past, a tabulating center was set up in each state, using everything from adding machines to small computers. On the night of November 5, there will be reporters at the precincts, and other reporters at each of 4500 county, city, and town centers. They will telephone Los Angeles, Dallas, Atlanta, Chicago, Cleveland, Philadelphia, or New York. At these seven regional centers, the returns from each precinct will be taken by a telephone operator on a report form and coded by state, by county, and in some cases by city as well. A keypunch operator will punch the information, which then goes to one of 23 card readers. Information will be fed by high-speed circuit lines at 42 cards per minute into the national NES center in New York, which is a separate operation from the New York regional collection center. The national center will be at the Associated Press offices in New York, with information feeding at 1050 bauds into 23 paper-tape punches. The paper tape goes at 105 characters per second (c/s) into two IBM 360/40s, one backing up the other, which the AP normally uses to transmit stock tables.

As a second backup to this input operation, the regional centers will transmit county-level and state-level returns by teletypewriter over other telephone lines to the national backup center, where the information will dead-end unless the card-reader input or the computer systems malfunction. The national backup center operation will be in another building entirely. Each regional center will have its own backup system to add state totals for more redundancy.

The national NES computer (Fig. 1) will do the following: total up by county the vote for President, senators, and governors everywhere in the nation; total up congressmen by congressional district; total up by state the vote for President, senators, governors, and congressmen; and, finally, total up the national presidential vote

FIGURE 1. Raw-vote data inputs to the national NES computer used in determining projected election results.



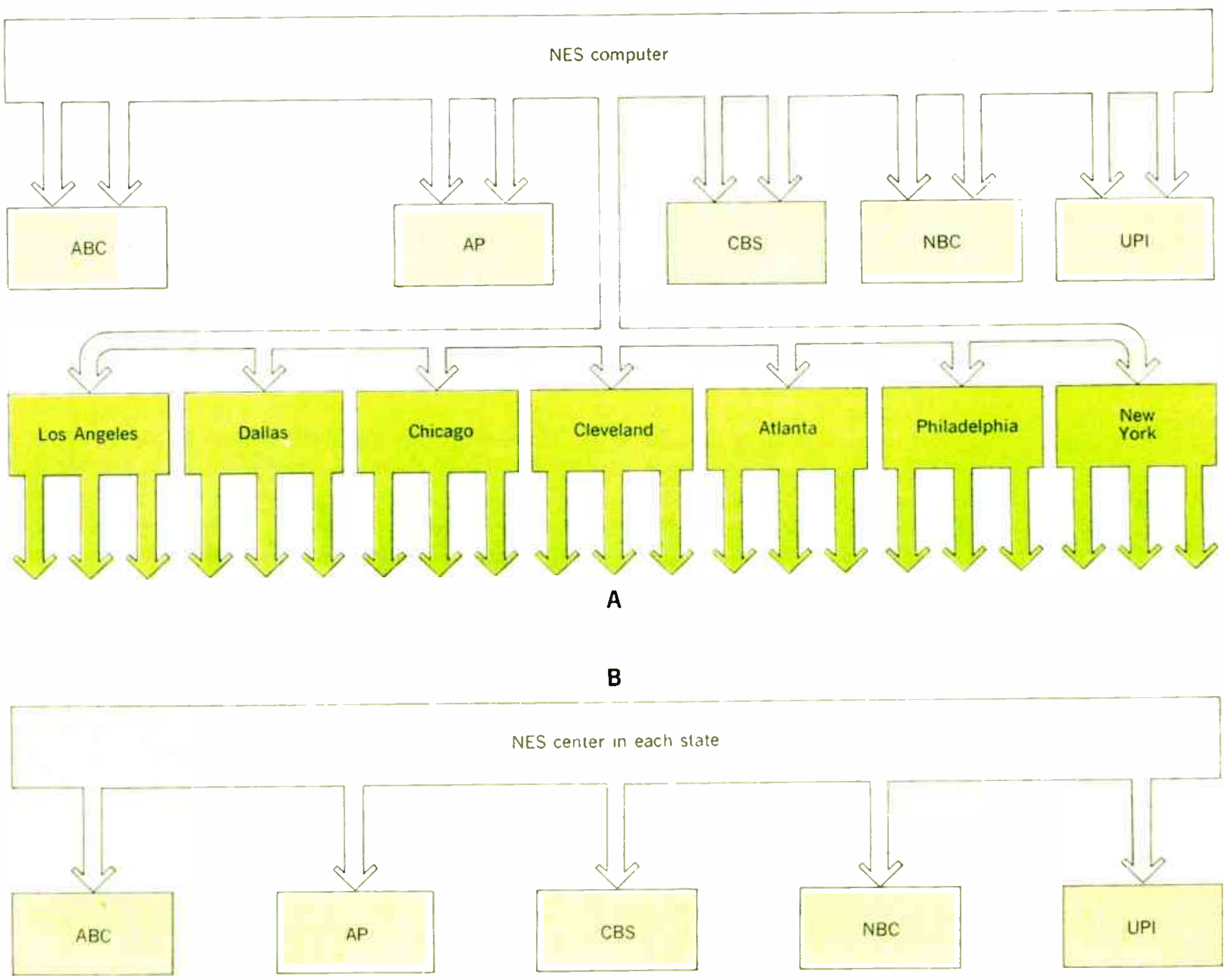
Every 15 minutes, the computer will release the county-level figures (or city-level figures, if that is the applicable unit). The computer will release the state totals every five minutes. And the national presidential totals will be released every minute. The NES is programming to expect as many as four presidential candidates, assuming that George Wallace and perhaps a peace-party candidate may be on the ballots. In addition to vote totals and identifying codes, each message will give both the number and the percentage of precincts reporting.

Output from NES will be on two levels (Fig. 2): computer to computer and computer to teletypewriter. The computer-to-computer delivery will be through American Telephone and Telegraph (AT&T) data sets operating at 105 c/s, 1050 bauds using a ten-level code in U.S.A. Standard ASCII. This feed goes to three of the five NES members (ABC, CBS, and NBC), and is for analysis and vote projection only, not for reporting vote totals. The wire services have no need for this feed. The vote totals on tally boards that you will see on the television screen or hear on radio will come from computer-to-teletypewriter feed, with the computer driving teletypewriter transmitters.

Twenty-four teletypewriter circuits will carry vote returns to each NES member. At ABC, we will get the information at two separate locations—one for posting on tally boards using Solari numbers controlled at electric consoles, and one for analysis. With spares, we will have 54 teletypewriter printers allocated for just this aspect of the election-night system. But we're not done yet. The information about Wisconsin and Arizona and New Jersey and Alaska must also get back to Wisconsin and Arizona and New Jersey and Alaska. Fourteen data-speed circuits feed the seven NES regional centers, which in turn—using paper tape—drive teletypewriters in each of the 50 states and the District of Columbia. And at each of the politically important state centers, ABC will have a political analyst—a political scientist who specializes in that state's politics. He will pay special attention to those county-level reports. We at the ABC center will not see this information. We would drown in paper if we tried to analyze the returns constantly coming in from every county in the nation about every major race; also, a political scientist in Wisconsin knows a lot more about the counties of Wisconsin than people at a national center.

To sum up the flow of the raw-vote data, which we use for our tally boards and for our projections and analyses, first the raw vote is collected by NES. With a reporter in most of the nation's precincts, the returns are phoned to seven regional cities, transmitted by card readers through telephone company circuits to New York, and

FIGURE 2. A—The output of the NES computer. B—Outputs from the NES center in each state.



there processed and delivered to the computers and the teletypewriters of the broadcast networks and the news wire services, and to teletypewriter locations in each state of the union. This is one source of election-night information.

Another source of information is available to us before the first vote is counted. We call it our baseline (Fig. 3). It is, in fact, an educated guess made by our state and national political analysts based on opinion polls, past voting patterns, and other sources of information that indicate what to expect. As guesses go, our baselines have proved to be reliable indicators of the range in which a candidate's vote will fall.

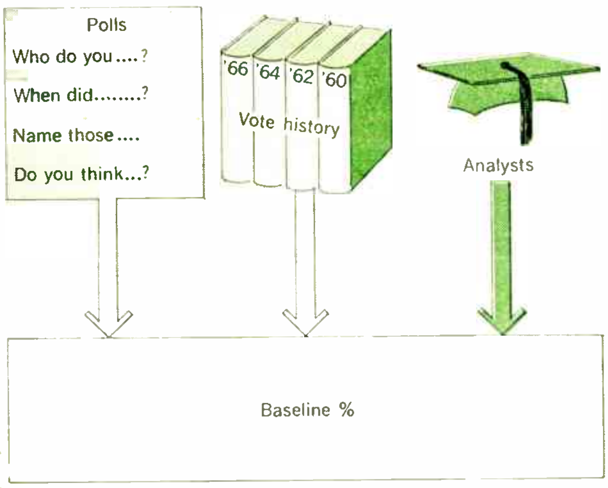


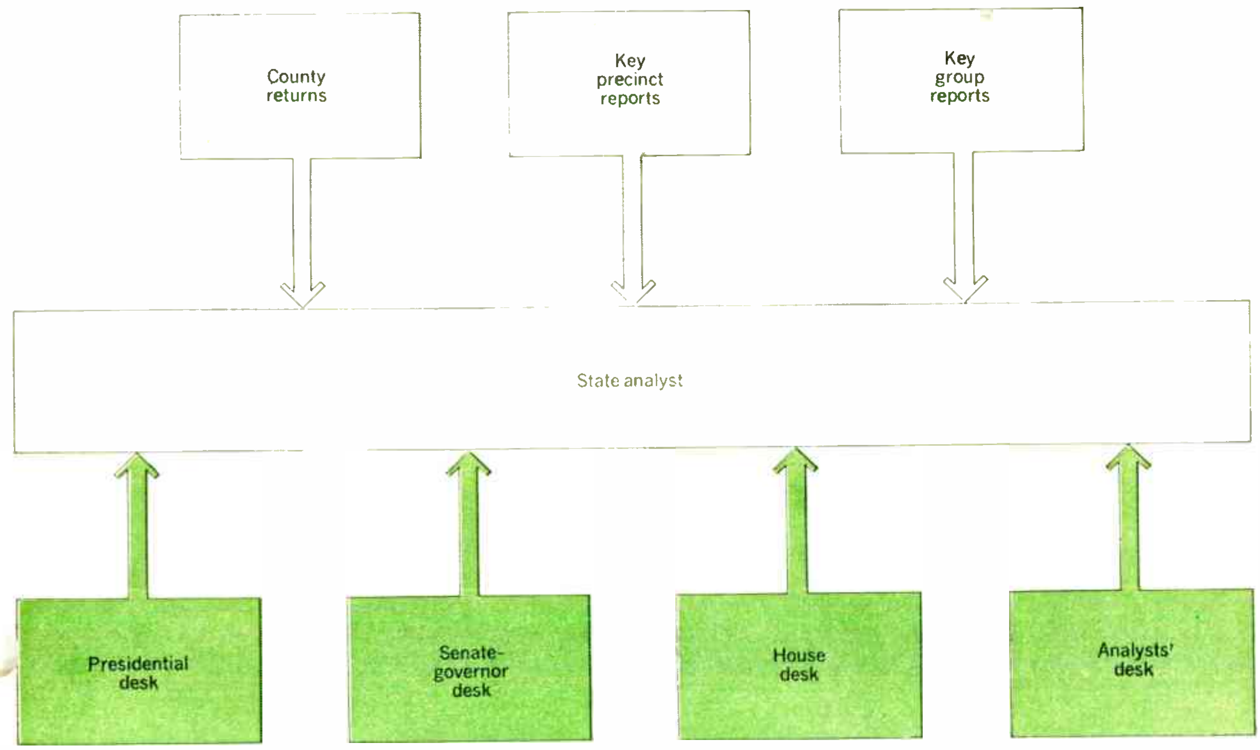
FIGURE 3. Determination of baseline percentages.

A third source of information on election night is the state analyst himself, and whatever supporting people he has (Fig. 4). Remember, he alone in our information network gets county-by-county returns from each contest in his state. If a heavily populated county is slow in reporting, for instance, he will be more cautious in reaching a judgment in a race which is running counter to the normal trend in that state. In 1966, for example, a blizzard slowed vote returns from parts of South Dakota. The computer that counted the IBM Votomatic cards in DeKalb County, Ga., was down for hours, halting the returns from many suburbs of Atlanta. The late voting in Baltimore, Md., was especially heavy in the 1966 governor's race. These are the kind of conditions with which our analysts must contend. On election night, each state analyst will confer separately with the presidential decision desk, the Senate governor decision desk, and the House decision desk, plus additional phone conferences as needed with the analysis desk, which probes into the voting patterns of what we call "key groups" (you might refer to them as "voting blocs").

We now have three sources of information feeding into our information center: raw vote, baselines, and state analysts. There are also some minor sources, such as AP and UPI reports of voter turnout, which, with spot phone checks, regulate the coefficients of the elements that comprise our statistical model. There is a fourth major source of information, perhaps the most valuable of all (Fig. 5). It is our key-precinct operation. The ABC total isn't final yet, but it will have more than 2000 keys across the nation. A state with a small, relatively homogeneous population, such as Delaware or Wyoming, can be represented with a model consisting of 30 keys. A large, complex state, such as California or New York, will need 100 or more.

Now, 2600 key precincts means 2600 reporters. Wher-

FIGURE 4. Information sources available to the state analyst.



ever possible, we prefer two reporters to go together, so this means we are looking for something of the order of 5200 reporters. Based on experience, ABC contracts with Leagues of Women Voters to provide reporters. They are mature in a situation in which people are sometimes very touchy. They are intelligent. They are dependable in a situation in which failure to do the job could bias a sample. And they are as concerned as we are about bringing home to the public the importance and interest of elections.

However, League members are not journalists. This necessitates more organization and effort. They must be told how to arrange in advance to get precinct returns, which is more complicated than one might imagine, because election laws differ from state to state; how to get partial votes when the count is slow; and what to do about telephones. This too is complicated; ABC installs a lot of telephones just for one phone call. During the Alabama primary in 1966, the last election in that state, a League reporter was denied permission to use or install a telephone at a remote farmhouse. So she went outside, looked up and down the road, then called us to order a telephone installed in a nearby oak tree. I didn't hear what the telephone installer said when he got that order, but I can imagine. Nevertheless, he put it in. On election night, she got her voting information, went out to her tree, and phoned New York.

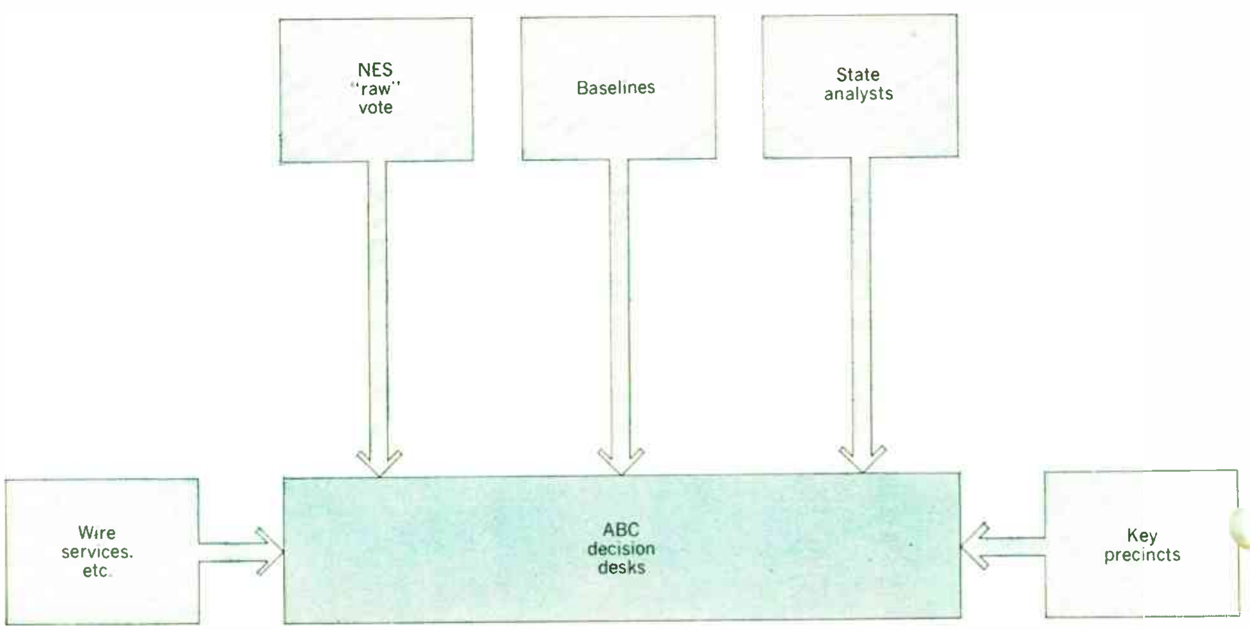
The remoteness of a precinct is a problem in terms of finding a reporter to cover it. We have hazardous precincts—a few in the rural South, many in urban ghettos. I bring these matters up to point out that human factors loom large in our information-flow planning.

On election night, reporters will phone our ABC election-night center at the ITT data-processing offices in Paramus, N.J. The first calls will probably come from Kentucky, which has voting machines, and polls that close at 6 P.M. At 6 the next morning, 12 hours later, we'll still be getting some calls from Alaska and Hawaii. Reporters will be phoning one or more times about 51 presidential races, for, under our electoral system, we have 51 contests—comprising each state and Washington, D.C. There are also 21 gubernatorial races and 34 senatorial races. Each race may have two, three, or four major candidates.

At Paramus, the calls will be received at a 54-phone-position rotary. The telephone slips will be keypunched with the code number for each precinct, the number of each race, and the raw-vote figures. Messengers take the cards to our prime system card reader, then to our backup system card reader, and then to our secondary backup system card reader. If a card is rejected for some reason—say the total vote exceeds the registered vote of any precinct in that state—a phone call is routed through a League of Women Voters state coordinator in that state to the reporter. Heretofore, we have asked the reporter to wait for half an hour at the precinct, but we learned that at some polling places everyone else went home, leaving our reporter alone and shivering on a November night on a street beside a pay telephone, waiting for a phone call that never came. This time we've arranged to track her down at home, or even at an election-night party.

The second source of input to the computer will be from NES teletypewriters carrying presidential, senatorial, and gubernatorial statewide raw-vote returns. These will also be keypunched and fed into the backup computer. Remember, the prime computer is getting the information at dataspeed on a computer-to-computer feed. Its line printer will produce printouts of many kinds, which will then be distributed to the presidential decision desk; the Senate–gubernatorial decision desk; the audit desk, which continues to monitor races after election trends have been set and decisions have been reached and announced so that if a race takes an unexpected turn or a wide lead unexpectedly narrows (and this has happened before), we have a desk monitoring these races; and the analysis desk, which examines key group breakouts and regional summaries. The House desk assists our political

FIGURE 5. Major sources of information from which a network's decision desk formulates its election projections.



analysts, who are following and calling the races to fill congressional seats. We have three internal teletypewriter wires of our own: the ABC red wire carries the names of winners when they are determined; the ABC green wire carries analysis and other significant or interesting election news; the ABC O and O wire carries both kinds of information to ABC-owned stations in New York, Chicago, Detroit, Los Angeles, and San Francisco. The red and green wires go to the ABC radio network, to the studio in Manhattan from which William Lawrence reports, to the studio in Manhattan from which Howard K. Smith reports, to control rooms where producers determine what remote locations to fire up—that is, whether to switch to a ballroom in Atlanta where Herman Talmadge is about to appear or to switch to a ballroom in Illinois where Everett Dirksen is about to appear. These choices must be carefully weighed so that we appear electronically where the action is hottest.

Selecting a sample of key precincts

Irving Roshwalb

Other participants in this seminar will describe the model to be used on election night to anticipate the results of the election early enough to be reported to the large audience of listeners and viewers who are waiting to see if they have picked the winner. Only two voters in recorded legend have played it cool concerning their vote and were able to resist waiting around to see what would happen. Both of these men, in the legends, simply voted and went to bed. One, Charles Evans Hughes, went to bed President and woke up a near-miss. The other, Harry S. Truman, went to bed a near-ex-President, but awoke with the rural vote to find himself still in office.

One of the critical elements in the election-night model is the flow of information on the swing or shift in each party's vote in a sample of election precincts. This sample of precincts is what is referred to as the "key precincts." The fact that the purpose of the model is to anticipate the final outcome of the election leads to heavy reliance on the vote results from those precincts that arrive at the computer first. If the votes in all precincts could be tallied immediately after poll closing, and these tallies could be made immediately available, then a simple random sample of precincts could give a precise measure of the election's outcome. In such an ideal situation, the selection of a key-precinct sample is a rather simple matter. The facts of life are a bit harsher.

Results from some voting units are available almost immediately. Other units don't report for many hours. So, on the basis of past experience with the availability of the precinct's election results, plus a reasonable guess to its availability on election night, 1968, ABC was able to rank all election precincts in a state in terms of the likely time of the reporting of the results. Some precincts, because of their history of late reporting, or because the local officials would not cooperate, were eliminated from consideration.

The immediate consequence of this definition was to restrict the universe of precincts. The degree of restriction varied with state and area. The simplest situation was the District of Columbia, where all voting is by machine and the data are available. One of the more restricted areas was Indiana, where only 63 percent of the voting population was available. The average percentage available was about 75–80. To draw an unrestricted random sample of such constrained universes could be to invite disaster. Instead, we drew a purposive sample for each state—one that matched the universe as nearly as possible in terms of those characteristics that bear the closest relationship to the probable outcome on election night.

The general procedures were the same for each state. The actual steps taken varied somewhat with the condition of the materials from which the sample was to be drawn. The procedure for selecting the sample called, first, for drawing a sample of communities with probabilities proportionate to the size of the voting-age population. The precincts within each selected community were then drawn with equal probability. In this first step, the precincts were selected across the state, without any restrictions concerning the availability of the data on election night. The total number of precincts drawn was actually twice the number we expected to end up using in the final sample of key precincts. The size of the sample drawn varied from 15 key precincts to 100, depending on the uniformity of past election results and the kind of reporting detail that might be required on election night.

The precincts drawn in this way were classified by city size. Then, each of the precincts was investigated to determine its past voting history in a number of elections. This investigation led us in many directions, all at once.

First, the reporting unit we were interested in was the smallest unit for which election results were reported separately. We chose to call this unit the precinct. The name of this unit, however, varies by state—it's an election precinct in some, an election district in others, a ward or a beat in still others. In some states, the results for past elections are available in neatly bound volumes that can be purchased simply by sending a check along with your request. In other states, statewide results are located in central archives and research workers can simply sit down and copy all the data required. In some states, the data are available only at the county level, and in others at the local level. The condition of the records ranges from beautiful shelves to dusty files in a basement corner. In several states, one of the major political parties is the only source of precinct information and only special pleading can release the data. In one instance, the local printing contractor was responsible for storing the records, and in one final example, the precinct results for one election had already been burned.

Once the results of the past elections were in hand, we recorded the "percent Democratic" for each election as well as the shift in "percent Democratic" between specified elections. The full sample of precincts could now be classified by city size and "percent Democratic." Using these cells as a description of the universe of precincts, we then proceeded to cut back to the desired sample size. Obviously, the first precincts eliminated were those that could not be counted on during the election-night coverage. "Not be counted on" meant no chance of reasonably early reporting or the refusal of local officials to cooperate.

Further changes were made to arrive at a sample of the required size, distributed according to the description of the universe provided by the first large sample of precincts. For this sample and for the appropriate past elections, two sorts of averages were computed:

1. The "barometric"—the average "percent Democratic" in the sample precincts.

2. The "swing-o-metric"—the average shift in "percent Democratic" in the sample precincts.

Both of these sets of data were then compared with the statewide results. If the comparisons showed discrepancies of more than two or three percentage points, substitutions were made to bring the differences within this range.

This completed the first stage of the research on the key precincts. At this point, we knew that the sample for the state reflected, in a reasonable manner, the city-size distribution of the population, as well as the past voting behavior of the electorate. The second stage of the investigation involved learning considerably more about the constituency of each precinct. The reasons for this were threefold:

1. To make sure that the sample of key precincts matched the universe on characteristics other than those we could get from the voting records.

2. To describe the key precincts in such a way as to make them useful in trying to trace how different groups of voters cast their ballots on election night.

3. To obtain the exact addresses of the polling places involved in the key precincts so that ABC's representatives could be directed to them on election night.

The second stage, then, involved obtaining the following kinds of information for each key precinct:

1. *Ethnic and racial makeup.* This varied by state. In New Hampshire and Maine, the incidence of French-Canadians is important; in the Southwest, Mexicans; and Negroes in the South and in the major urban centers of the North.

2. *Religious makeup of the population.* Again, this varied by state, and because of careful planning, Mormons were carried in Utah and Idaho.

3. *Income.* The major concern here was to locate poverty areas and very wealthy areas.

4. *Labor union membership.*

5. *The exact location of the polling places in the precincts.*

In addition, respondents were asked to offer any comments on what they thought made their precincts unique, or at least unusual—new housing developments, urban renewals, etc. In order to do this, a special questionnaire was set up for each precinct and sent to interviewers who contacted a variety of local people who should know the precinct. Our respondents in this phase of the research included congressmen, local party workers, district leaders, election officials, and parish priests. In many cases, several interviews with different people were required to answer all the questions. Because this classification will help the reporters on election night to say, "Voters in predominantly Negro precincts have voted for . . . ," "Don't know" responses from our contacts could not be accepted. Interviewers kept searching for respondents who knew their precinct well enough to give a response.

One last problem faced us almost everywhere—redistricting. Much of this caused no problem. Redistricting was usually carried out on the congressional district level, calling only for a regrouping of election precincts. In some places, such as Milwaukee, precinct lines were redrawn, effectively wiping out past election data. The problems caused by redistricting are still with us. Some states are still in the process of redrawing precinct lines and the problem will probably remain until election night.

The solution that we finally chose was to plot precincts on "census block" and "census tract" maps and to correlate past election results of the precinct with characteristics of the population in the blocks and tracts in the precinct. Using these correlations we were able to estimate past election results for the new precincts.

The net result of all of this is a set of 51 different key precinct samples, one for each state and the District of Columbia. And as we submit these samples to the tender care of the electorate, we hope that they, and the computer, will treat them as gently and as kindly as they have in the past.

Mathematical and computational considerations of the election-night projection program

Jack Moshman

Prior to election night, a large amount of background information will have been collected, analyzed, summarized, and placed in computer memory for use by the projection program that evening. These data include such information as past voting history, registration facts, descriptive information about candidates, poll closing times, and past voting trends. These data are to be punched on cards and stored on disks as part of the basic information bank.

On election night, the live data coming into the ABC operation will originate at precincts throughout the U.S. and will be fed into the machines in different ways. It is interesting to note that the United States now covers six time zones ranging from Eastern Standard to Bering Standard Time. The raw-vote information originating from the NES national lashup is available on a national, state, county, and, in some cases, city basis. It will be transmitted on four 1050-baud lines on a computer-to-computer basis from the NES computer to the ABC system. These lines will be identical to the lines entering the other networks; all data will be transmitted simultaneously to all networks.

Key-precinct information, coming exclusively to ABC, will be telephoned into the ABC computer center by precinct reporters from all 50 states and the District of Columbia. There, results will be taken down by telephone operators and keypunched for entry into the computer. Certain control information, including the entry of "calls" of races that have been made and interrogation of the updated vote information of the data bank, will be entered through display consoles scattered about in strategic spots in the ABC operation.

We thus have a collection of various types of information arriving simultaneously in four major equipment modes: the computer-to-computer lines from NES, keypunched data from the key precincts, interrogation consoles, and teletypewriters. The output will be in any one of two major forms: (1) line printers will be used to print summary data and lengthy tables; (2) cathode-ray tube displays will be used to answer inquiries and provide tabular output of limited extent. Past experience has convincingly demonstrated the desirability of reducing the amount of paper flow to the extent practically possible. Where a feasible alternative exists, the display scopes will be used in preference to the line printers.

The heart of the ABC system will be an IBM 360/67 located at the ITT Data Processing Center in Paramus, N.J. A complete 360/65 backup system will be available that night in the event of any sort of computer misbehavior. Certain items may be switched from one machine to another, which enhances the total flexibility of the operation.

There are few applications that are so dependent upon dependable, reliable operation at one single time as is this; space shots have been scrubbed, even payrolls have been late, but I know of no time an election has been deferred.

The major sources of traffic that will be carried into the machine, as indicated earlier, will originate either from the NES lines or from the ABC key precincts. A reasonable estimate of the amount of information that will be coming over the NES lines is about 18 000 characters per minute. Key-precinct information is of necessity much smaller and much more specific. We estimate that this will total some 150 000 to 200 000 characters, peaking very markedly during the period from 8:00 to 10:00 P.M. EST.

I would now like to describe some of the salient points in the mathematical model that will be used in order to transform the election data coming in on that first Tuesday after the first Monday in November into projections that will be sent out over the air.

Any reasonable projector should take into account as much of the fund of information as is available to him at the time a projection is being made. In this particular case, this fund of information includes opinions, informed comment, and the many pre-election polls that are available prior to the election. The composite of this information goes into what we call our baseline projection. The baseline itself is a valid estimate based upon these pre-election sources of the outcome of each contest in which we are interested in every political subdivision specified in our mathematical model. Depending upon the political situation and characteristics within a state, we are interested in the results identified down to the county level, groups of counties, major metropolitan area, or, in some cases, an entire state. In no case do we omit the state level itself.

The baseline projection is, in effect, our time-zero projection or starting value. We have found historically that this information is itself rather good and gives reasonably close estimates to the overall outcome. Obviously, as one goes down into finer and finer political stratification, the precision of these estimates is likely to be poorer and poorer in a relative sense.

It is important to distinguish between projecting who the winner in a race is expected to be and what the actual vote split will be. In a completely one-sided race, where the winning candidate may get 65 percent of the vote, the chance of being ten percentage points off does not inhibit one's confidence in naming the winner. On the other hand, in a very close race, where the winner will win, say, 51 to 49 percent of the vote, being two percentage points off in the wrong direction can spell the difference between being a pundit and being a charlatan.

As the evening begins, we receive a few scattered, generally meaningless, results from those odd precincts that close early or have some special characteristics such as the few rural precincts in New Hampshire that characteristically vote at midnight, get all 12 votes counted, report them, and then go to bed. In some cases, some partial returns are available from precincts that count and report the vote cast up to until, say, two o'clock in the afternoon. Partial returns are a very difficult thing to analyze, since we lack a valid basis for comparison. More and more states are beginning to prohibit partial returns by law.

Ordinarily, the first real returns that come in to ABC are those from the ABC key precincts, which are phoned in directly by reporters in the field to the central ABC headquarters. These precincts begin to unfold a pattern and the projection model then combines the baseline projection with the key-precinct information in order to obtain what hopefully is a better combined estimate than either one would be itself. We do not throw away and discard completely the fund of information that went into the baseline.

In combining these two estimates one must take into account, as we do, both the number of key precincts that have reported and the consistency of the pattern they show in the swing from the last comparable election to the present one. The greater the consistency and the greater the number of precincts reporting, the greater the relative weight given to the key-precinct estimate compared with the baseline. In any event, we continue to maintain the baseline component as part of the overall projected estimate.

Now, as the evening wears on, the actual raw vote is beginning to come in over the NES lines. It is identified by the state, county, or metropolitan area from which the vote originates. This raw vote provides another estimate of what the final outcome will be.

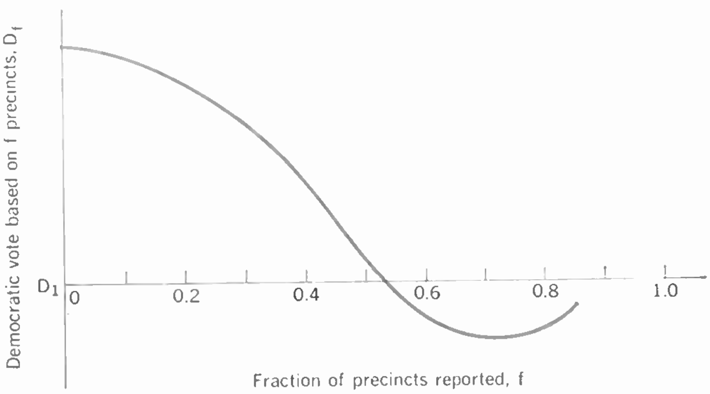
We have found, though, that based upon historical voting patterns, certain areas will habitually favor one political party relative to another in the early returns. If one has a fine geographical breakdown of the source of the vote, one can compensate for this in the model. However, the practicalities of the situation and/or the collection process may make it necessary to treat the vote from the state as a whole. We are able to make the needed compensation by using what we have traditionally called μ curves. A somewhat exaggerated μ curve is shown in Fig. 6. This represents the typical departure from the final result as a function of the proportion of the total precincts in the state that have been reported.

Thus, early in the evening one might expect a heavy concentration of Democratic votes, which continues but narrows down so that when 50 percent of the vote is in, the result tends to match the overall final result. In between 50 and 75 percent of the precincts, there is a slight overtaking by traditionally Republican areas, so that there is a small Republican bias. After 75 percent of the precincts have reported, the discrepancy disappears and the resulting vote then is unbiased in the sense that there is no strong pattern favoring one party over another. Corrections based upon patterns of this nature for those states for which it is significant are introduced into the model in order to adjust the raw vote.

Having the μ curves going down to zero as the number of precincts approach 100 percent does not always take into account the absentee ballots in a state. In 1960, California had a significant number of absentee ballots that were predominantly cast in favor of Nixon. That year Kennedy carried the state according to the vote cast on election day, but the electoral votes were given to Nixon when the absentee ballots were added to the election-day vote itself. I recall from my own experience that year that we had projected the state for Kennedy and were wrong, we found out afterward, because of the absentee ballots. Now the practice has changed in California to count these ballots early and report them along with the votes cast on election day, but it was then a fine point that had just never occurred to me or to my colleagues at the time. Not anticipating this, we were stung. It is by being stung in ways like this that one learns—sometimes it means learning the hard way.

In deriving the μ curves, which are empirical in nature, one must take into very careful consideration whether or not there have been any changes in voting patterns resulting from the introduction of voting machines or changes in the poll closing times. Where there are such changes—and in every election we find that there are some—the μ curves have to be suitably adjusted in order to render them suitable.

FIGURE 6. An example of a μ curve, depicting the Democratic turnout based upon fractional returns of election precincts.



Thus, we now have what amounts to three different independent estimates of the result: the baseline, the results obtained from the ABC key precincts, and our analysis of the raw returns coming in from NES. The three estimates are then combined in order to provide a still better overall estimate. Relative weights are dependent upon the factors mentioned before insofar as the precincts are concerned. Insofar as the raw vote is concerned, our best weighting factor depends upon the proportion of the total precincts in the political division that have reported. Any reasonable weighting procedure should have the weights of the baseline and of the key precincts going to zero as the number of precincts in the state reporting goes toward a 100 percent of the total number of precincts.

Mathematically, the projection equation looks like the following:

$$P = \alpha B + \beta K + \gamma R$$

where $\alpha + \beta + \gamma = 1$; P = the projection; and B, K, and R are, respectively, the baseline, the key-precinct, and the raw-vote estimate. The Greek letters, alpha, beta, and gamma, are the relative weights (which must add up to one). The conditions mentioned say that as the number of precincts approaches 100 percent in any political subdivision, then alpha and beta go to zero, and gamma approaches one. When gamma is zero, which obtains when no raw vote is available, then the relative sizes of alpha and beta, which themselves still add up to one, are dependent upon the number and consistency of the key precincts. Beta gets relatively larger as the number of precincts and the consistency increase. Consistency is measured inversely by the variance of the result from precinct to precinct. We are able to derive a confidence interval for the projected percentage of the popular vote for each candidate based upon the information that is being fed into the model. This information also enables us to obtain a measure of the probability that any individual candidate will, indeed, be successful.

Many will undoubtedly recall the game that was played in the elections from 1952 to 1960 during which time machines customarily reported out an odds ratio giving the odds derived in the machine that a particular candidate will win his respective race. Unfortunately, although this has a reasonably sound statistical basis, it is very easily misinterpreted and has been so misinterpreted by the viewing public at large. The odds quoted do not measure the degree of one-sidedness of a race but refer specifically to the likelihood that a particular candidate will end up with a winning margin of unspecified size.

For example, in the 1960 election, Kennedy obviously won. At some point in the evening, the cumulative electoral vote he obtained from states already decided was approaching or had passed the magic number, in those days, of 269. The odds were then infinite that he would win, even though the actual vote by which he won was very, very close. As a matter of fact, John Kennedy himself received less than 50 percent of the vote cast. So did Nixon. Although the difference was small, minor parties had drained off a couple of tenths of a percentage point, which gave us, strictly speaking, a minority President.

Projections are released over the air, both winners and the percentage of the actual vote that the candidate is expected to receive, after the group of analysts working with

ABC are convinced that the projection is sound, is based upon solid evidence received from reliable sources, and is confirmed according to everyone's opinion. Races with more than two candidates, such as we are expecting in November, where in many cases there will be four major candidates for the presidency and a number of the statewide offices, introduce various complexities into the model requiring the following of multiple candidates. Heretofore, we were able to adopt the relatively simple procedure of following one of the two major candidates and assuming that the other one receives the 100 percent complement of the first one's vote. The four-man race is not difficult to program, but it does introduce added complexity. Can μ curves be used?

We have built into our program an exhaustive set of validity checks to insure that the data coming in to us are valid and reasonable. Among the checks that are used are checks based upon the size of the vote and the fact that votes called in from key precincts have a valid and consistent code number. Precinct codes are released to individual reporters so that we are reasonably sure that it is a legitimate reporter calling in this vote, and at the same time they give us an error-detecting and -correcting feature. Telephone numbers are also kept under rather heavy security until the very last moment.

In the event that a return violates one of the validity checks, an error message is printed out telling us the nature of the check violated, and a special crew of people are responsible for chasing down this allegedly spurious message and either verifying that it is in fact correct or getting a corrected version of the garbled message.

We will be preparing a multiplicity of reports for use on election night. For most of what I say, you can consider that we will be doing things in triplicate. We will be interested in the presidential race in each state, as well as all the governors and approximately one third of the senators who are up for election. Our reports will be designed to enable us both to project who the winning candidate will be and also to estimate what the vote split will be.

One relatively minor item that I omitted earlier is being able to estimate the turnout, the number of votes to be cast in every state. On the basis of the turnout estimates and the projected vote splits, we will also be providing our commentators with estimated pluralities for their use over the air. In addition to winners and vote estimates, we are also concerned with projecting the electoral vote for the presidency and for projecting the composition of the Senate by political party as well as the party split of the governors of the 50 states.

Additional reports being generated by the machine will be of a type that will enable us to help analyze the vote, explaining where it's coming from, what it may mean, and identifying those demographic groups that are tending to vote insignificant proportions for one candidate or another. At times it may be that the insignificance of a particular demographic group might itself be news. If, for example, precincts that are heavily labor union in their composition should turn out not to be voting heavily Democratic, this, itself, may be news. Geographic breakdowns are an obvious addition that we will be providing the ABC commentators.

In addition to these output-oriented results—results that are aimed at getting messages, information, and analyses over the air—there are a number of utility-type reports that will be available to us to help speed the flow of information and make the interpretation more precise. For example, we will be able to find out rather quickly which precincts have not yet reported among our key precincts. We know the expected reporting time of these precincts. Those that have not reported by that time can be identified and suitable telephone checks made in order to accelerate these returns.

Our experience in 1966 among the key-precinct reporters working for ABC showed a vast variety of at times hilarious, at times tragicomic, events that took place which prevented the speedier return that we would have liked. One precinct reporter found the only available phone being manned by a teen-ager talking at great length to his girl. After waiting for what seemed to her an inordinately long time, she then walked a considerable distance to another telephone to make her report. As she later wrote to ABC, for all she knows that teen-ager may still be holding up the phone booth talking to his girl.

Another type of utility return is a reminder that identifies races that have not as yet been called, but for which a significant vote proportion has been reported, and/or the machine-calculated probability of being able to identify the victor has exceeded the threshold. In effect, the machine is saying, "How come?" Obviously, the decision for a call rests in human hands, but having the machine being able to identify what might have been an overlooked race because of the hectic pace of that evening, we think, will be a very handy device.

Each election adds to our store of knowledge. This particular one introduces a number of complexities that have not entered into a presidential race since 1948, with the appearance of significant third- and fourth-party candidates who conceivably might siphon off enough electoral votes to throw the result into the House of Representatives. If this should be the case in 1968, it becomes incumbent upon the television networks to recognize this early. It furthermore leads to a great deal more comment and interpretation of what the political realities might be in the event that the House of Representatives will make the final decision on behalf of the U.S. population.

We may find that, prior to the convening of the House in January 1969 in order to make this selection, we will want to build some completely new models in order to estimate what the House will do. Inasmuch as we're concerned purely with some 50 votes, since each state has only one vote in the House in the election of the President, I rather doubt that a mathematical, computerized model would be in order. We are, however, continuing to try to find out more and more how to interpret the results. We have some ideas that will be tried out for the first time in 1968 and already, on the basis of this experience, are gathering some information and further innovations that might not be used until 1970 or 1972.

These techniques being developed and being used on election night do more than satisfy relatively idle curiosity on the part of the U.S. population with something that, in any event, will be available free to one and all through all news media just a few hours later.

Projection techniques of the type developed for election projections have been adapted and used quite successfully in business and industry in order to project such things as sales during a model year. The analogy is really quite close. A good sales manager will provide an accurate baseline projection based upon what he knows and the experience he has gained. The raw vote amounts to the normal reporting pattern of monthly reports of sales in each district or region encompassing the sales territory for a company. At the end of the model year, when all returns are in, one knows the result exactly. The analog of the key precincts can be found by careful sampling of dealerships through out the U.S. Getting the information on their sales quickly and directly, bypassing the usual reporting patterns, provides an early estimate that, based upon the statistical procedures underlying the sample, can be quite accurate. It is a type of technique that has seen successful use. It lends itself to considerable adaptation and to quite a wide variety of applications.

The contribution of political science to election-night coverage

Donald G. Herzberg

As I read the comments of my colleagues, I pondered long and hard over just what it is that political science and a political scientist can bring to network election-night coverage and to the months of agnonizing labor that goes into preparing for those ten or eleven hours of air time. This is not to say that we political scientists are an especially modest lot. We are not (as Jess Unruh of California says, "modesty in the face of ability is hypocrisy"). So just what are the special qualities and what is the contribution that my colleagues look to from my profession?

Certainly, political scientists ought to bring objectivity to election coverage. This does not mean that as political scientists we don't have our preferences as to who our leaders should be. I happen to run an Institute of Politics. My job is to get college students involved in politics. In that pursuit, I can hardly not set an example and be involved myself. But I must and do play fair. So too on election night, I must try to put aside my own involvements and attempt to bring to bear to the problems in a dispassionate way whatever insights, experiences, and expertise I have. Many years ago, when I was involved directly in politics, I worked for a U.S. Senator, Bill Benton of Connecticut. I remember one election night when he was running. I was an election judge selected by my party to be at the polls in Middletown. One of my jobs was, as soon as the polls closed, to join a representative of the other party and an election official and open the voting machines. If you are knowledgeable about politics in an area, it is possible to learn the results in one election district and know whether you have won or lost. We opened the back of the first machine and I held a flashlight so we could read off the numbers. It was clear that we had done so much worse in that district than we had done before that there was absolutely no hope of winning the election. I sadly turned the flashlight over to a friend who was standing by and left to take a lonely drive to Southport where Bill Benton lived in order to be with him.

In the business I am in now, there is no one to turn the flashlight over to. Whether or not you like what you hear and see, like Bill Klem, "You've got to call 'em as you see 'em." Well then, what is it that I attempt to do? There are at least eight ways in which I seek to make a contribution.

The first way has to do with the delicate art of preparing the baseline. Dr. Moshman has already discussed and defined that baseline as a valid estimate of the outcome of each election contest we are interested in based upon pre-election polls, opinions, and informed comment. Here, a political scientist's knowledge of previous election history, his awareness of special election races that may raise or lower voter turnout, his contacts with political scientists within the state, his friendship with politicians who may be able to offer realistic help all make up the political scientist's contribution to the manufacture of the baseline.

A second contribution relates to the rare case of a computer breakdown, either completely or for a part of the evening. This brings to mind Herzberg's first law—if there is a chance for a computer breakdown, there will be a computer breakdown. In times past, I might have said that in jest, but some years ago, before I came to ABC, I was involved in exactly that horrendous situation. That night it was the knowledge of political scientists that kept the network in the ball game. To paraphrase *Variety* magazine's comment about the event, if it hadn't been for a handful of political scientists, the evening would have been a disaster. I agree; if it hadn't been our ability to take returns phoned in by our reporters and to interpret them immediately, we would have been in bad shape.

A third contribution is concerned with the political scientist's ability to explain any discrepancies in key-precinct returns and suggest ways in which to make allowances for these discrepancies. For example, we might get a labor key-precinct return from Hartford, Conn., that shows a heavy Democratic majority at the same time that we get a return from a Waterbury, Conn., labor key precinct that gives a modest Republican majority. All things being equal, all labor precincts ought to be going the same way. But in this case, the political scientist is able to offer the suggestion that the Hartford precinct is composed largely of UAW Union members, whereas in Waterbury the Brassworkers Union is the dominant force. The UAW has a more solid commitment to the Democratic Party, and they perhaps have a better record of getting their membership registered and voting than do the Brassworkers.

Furthermore, because these two returns from Connecticut will be coming in very early in the evening, since the Connecticut polls close at 8 and the state uses voting machines exclusively, the political scientist may be able to suggest which of these two labor precincts is the more typical and the one most likely to be supported by other labor-precinct returns from the states that will come in later. This is just an example, but in the course of an election evening there are literally hundreds of opportunities to bring to bear political science knowledge on the key-precinct returns.

A fourth contribution deals with the raw vote. As Dr. Fang has explained, all three networks work with the same raw-vote returns in a cooperative nature along with the two wire services. The great drawback to using NES raw-vote returns too early in interpreting elections is that there is no official way of knowing where those returns in the various states come from. Were they, for example, from traditionally heavy Republican areas, which would explain why the Republican candidate is far ahead on first returns while at the same time our key precincts are showing a close race or a Democratic victory?

In some cases, I am likely to know from experience and knowledge of the states' voting pattern where these returns are from. If I don't know, I have the opportunity to call other political scientists who are standing by in the states. What I don't know, they may well know. For example, in 1966 in New Jersey, early raw-vote returns showed Senator Case with a huge lead. I knew that these returns came from normally Democratic areas. At the time our key-precinct returns were not sufficient in numbers to suggest the landslide proportions of Senator Case's victory. But, on the basis of these early raw-vote returns, we were able within minutes of poll closing to project a tremendous majority for Senator Case. Now, here, obviously, it was not projecting Case's victory that was significant—everyone knew that—but it was projecting the size of that victory that was significant.

One must be careful, however, in using raw-vote returns and trusting them too completely. In the recent New Hampshire primary, our key precincts were, relatively speaking, slow in coming in. This is not surprising since the New Hampshire vote is almost completely by paper ballots. On the basis of the raw vote as it mounted during the evening, I held out in our brain trust discussion with my colleagues for going with the raw-vote distribution. Senator McCarthy had stood at 36–38 percent for several hours. My colleagues working with our key-precinct returns believed that ultimately Senator McCarthy would go over 40 percent. Fortunately, their arguments persuaded me that they were correct and I gave in as gracefully as a political scientist can. They were right, and I and the raw vote were wrong. What had happened was that NES had underestimated the total vote in the Democratic primary and during the last half of the evening kept raising it, and that vote was coming from strong McCarthy territory.

A fifth contribution made by political science is in the work of political scientists stationed in a number of critical states. I alluded to them a minute ago when I was discussing the use of early raw-vote returns. These political scientists are chosen early in the election year. We use them constantly to provide intelligence reports to the ABC election research unit. Their service on the weekend before election day, when we feed the baseline, is invaluable. On election night, we have a direct telephone link between them and our decisions desk. I can reach any one of them in a matter of seconds. We are in consultation constantly throughout the night. Before calls are made by us we check them out with the political scientists in the respective states. If, after a call is made, new evidence comes to them which suggests the situation is changing, they can and do call to alert us.

A sixth contribution we can make is to explain and make exceptions for unusual conditions that may occur which were not anticipated when the computer was fed and our baseline developed. For example, we may have to explain an unexpected light vote, or a heavy one in a particular area; or interpret the significance of a heavy or light vote early in the day which then assumes normal proportions; or interpret the impact of certain local election contests that may be unexpectedly affecting the way in which the vote is going; or perhaps explain the effect of weather conditions. I remember one call we were about to make in a western state. Only the vigilance of our political scientist stationed in the state stopped us. He pointed out that a sudden, unpredicted blizzard in a section of his state would dramatically reverse the decision our key-precinct returns seemed to indicate.

A seventh contribution is in suggesting the time has come to make a call, or perhaps the opposite, holding out for more data. Because of experience and intuition, or whatever it is, I normally find myself to be the fellow at the decision desk who says, "How about calling it thus or so?" This forces wiser and cooler heads to make a decision as to whether they agree that we have sufficient information to go with or call. On other occasions, admittedly rare, I will attempt to hold off a decision because of my own uncertainty even when my colleagues are reasonably sure that we can make a call.

Now that I have recited these seven areas, like someone at the confessional window, I feel considerably better about the contribution of political scientists to the process. But there is one final contribution of political scientists about which I feel particularly proud, and that is our contribution to the analysis of the event.

As far as I am concerned it is ridiculous for networks to compete and spend the bulk of their time in simply projecting winners. I realize that this seems to be the name of the game, and I like to win the race as much as anyone. To quote Jess Unruh again: "Winning may not be everything, but losing is nothing." But I honestly believe that far too much press and publicity are given to the network that makes its calls the earliest. I believe (and one of the reasons it is a pleasure to be associated with ABC is because they believe it too) that election-night emphasis ought to be placed not on the who's of election night but on the why's.

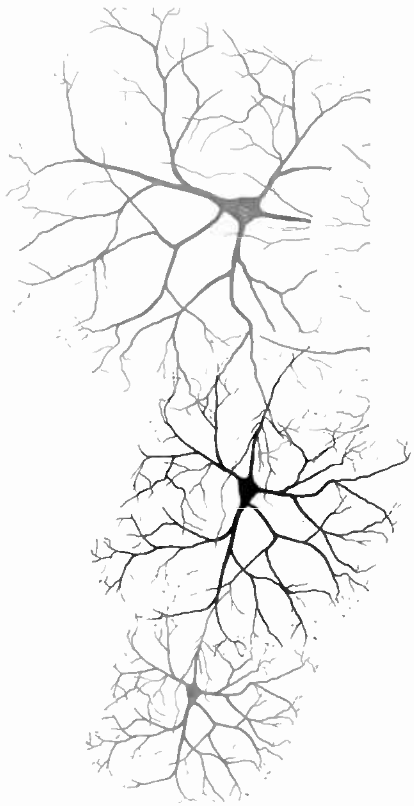
Frankly, it is, relatively speaking, a simple matter to make calls, but to explain those calls is where a network's responsibility really lies. That is the ultimate responsibility and the one in which we political scientists can make our greatest contribution. At ABC, analysis is principally the responsibility of my distinguished colleague Dr. Warren Miller, of the Survey Research Center of the University of Michigan. On election night, he has the task of explaining why the vote went the way it did, what it means, and what it portends for the future. For example, he can explain why the Negro vote went the way it did. He is able to compare that vote with the Negro voting record of previous elections. He can show where the shifts occurred and explain why. What he does in the way of explanations of the Negro vote he can do for other voting blocks—labor, low-economic, white-collar, and high-income groups, as well as Catholic, Jewish, and Protestant groups. He'll be able to explain what has been happening regionally; he will be able to interpret House, Senate, and gubernatorial elections.

This, coupled with intelligent projections of winners and losers with their pluralities, is the guts of the responsible network election-night coverage, and it is to this end that we political scientists strive, along with our colleagues from other fields and disciplines.

To understand brains

A new era in brain research, now 20 years old, has produced seas of neurophysiological data and an ever more complex and bewildering picture of brain functions. Eight experts in brain research and computer science talk about what can be hoped for in the way of understanding how the brain really works

Nilo Lindgren *Staff Writer*



"How do we go about understanding brains?" That was the fundamental question confronting the session, "To Understand Brains...," at the 1968 IEEE International Convention. This report on the views of eight session participants shows a strong consensus on three major points: first, that the popular analogy between brains and computers is ill-taken and perhaps misleading; second, that very little is understood about nervous system function, despite the accumulation of seas of data, and that present understanding is relatively restricted to events in the peripheral sensory systems; third, that the epistemological problem—what is really meant by "understanding" the nervous system—is especially difficult with respect to the staggering complexities in a system composed of ten billion cells, each of which might be regarded as a kind of hybrid microcomputer in itself. The cry for new concepts of the nervous system was especially strong, and though the participants did not regard the endeavor to understand brains as absolutely hopeless, their stress on the magnitude of the problems made their "realistic" appraisals seem quite pessimistic.

The quest to understand the functioning of the brain is an old one. Two thousand years ago, Aristotle proposed that the function of the brain was to cool the blood. Seventeen hundred years later, it finally became known that the brain is the seat of the intellect and control; and it was only 100 years ago that the brain was clearly defined as an electrical and chemical organ.

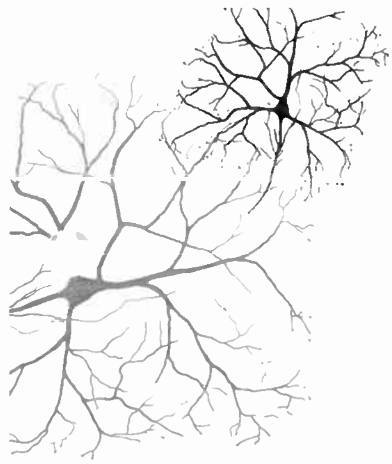
But something of a new era in nervous system research started in 1949, just about the time the digital computer was beginning to come along, with the development of a microelectrode less than a micrometer in diameter with which it became possible to measure the electrical activity in single nerve cells. These cells, or neurons, were viewed as the basic building blocks of the nervous system. Neurons grow like trees, their branches enmeshed and connecting in a confusing jungle; about ten billion of them compose the human nervous system. The figures show a highly simplified schematic of one kind of neuron, which has many dendrites (input connections) and a large number of branching outputs (axons). Early electrical measurements on neurons *in situ* revealed that the nerve cells seemed to fire an all-or-none electrical output along their axons, the major output channels or branches; it was this all-or-none pulse characteristic that was attractively and persuasively similar to the basic functional feature of the digital computer. Although subsequent intensive neurophysiological research has shown neuronal electrical events to be incredibly more complex than was at first imagined, the conjunction of a number of postwar developments—digital computers, information theory, microelectrode measurements, etc.—served to launch the concept that the nervous system was a kind of computer, a view that has become ever more popularly entrenched.

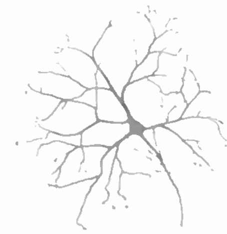
This new era of brain research, now 20 years old, has been a fruitful and also exceedingly "unnerving" one for neurophysiologists. For brain research has followed a path that might be compared to the earlier evolution of physics when investigators continued to uncover new particles and new physical phenomena, so that the need for some form of unified field theory became continually more pressing. Now, despite thousands of man-years of neurophysiological study, and despite the accumulation of mounds of data, the understanding of nervous system functioning is neither deep nor extensive. At the present time, this understanding is largely restricted to events at or near the periphery of animal sensory and motor systems.

Moreover, as the evidence accumulates, and the truly staggering complexity of nervous system functions thrusts itself ever more forcibly into the foreground of their attention, neurophysiologists have come to question increasingly the serious acceptance of any analogy between brains and computers.

An even more serious question confronting brain researchers is, in a sense, an epistemological one. What do they really mean when they say that they are trying to "understand" the nervous system?

Against this background of problems and questions, the 1968 IEEE International Convention held a session entitled "To Understand Brains...," consisting of formal papers and a panel discussion, in which eight participants





tried to answer some part of the following questions: How do we go about understanding brains? What is it that we need to do to understand ourselves in a mechanistic sense? And to do this, is it viable and useful to talk about computer–brain relationships, contrasts, and so on? Given the "horrendous" complexity of the nervous system, the deepest question that constantly recurs to thoughtful people, and to which each participant addressed himself, was this: How far can we hope to go? Is the goal of understanding, in fact, a hopeless one?

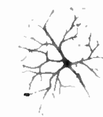
The participants were formally called upon to compare and contrast the relationships between nervous systems and computers at element, circuit, and system levels, and to place their emphasis on the unsolved problems of mechanisms, languages, and algorithms underlying neural action.

Organizer and chairman of the session was Leon Harmon of Bell Telephone Laboratories, an electronics engineer in communication research, who has spent much of his career trying to unravel brain functions through electronic models that closely mimic neural functions, and through analyses in theoretical neurophysiology. He has also worked on "intelligent" machines such as pattern-recognition devices. Harmon set the stage for the session through a brief, cautionary, and disquieting description of the kinds of problems now confronting brain research.

What is the neural language?

The crux of the problem in obtaining meaningful knowledge of nervous systems, Harmon began, is in understanding neural coding and decoding. Yet paradoxically, he went on, our comprehension of the language of nervous action is almost nonexistent. After 20 years of the microelectrode and the computer, we are barely off ground-zero.

Harmon cautions that an assumption implicit in the contemporary view of neural activity is that measured electric signals adequately reflect the operations essential to information processing. This could lead, he warns, to the further and perhaps dangerous assumption that electric potentials are the principal constituents of nervous system language. In a sense, he is saying that it is an historical accident that neurophysiologists are best prepared to measure *electrical* events in nervous systems, owing to the advances of electronics. Thus, it is at least conceivable, and should be regarded as an open question, that the electrical events may, in fact, be second order or artifactual. Even if the electrical events prove to be primary, they may not be the only ones. They may be supplemented, Harmon notes, by mechanisms already known—ionic signals, hormonal events, field effects—all of which may be quite influential. The information-carrying aspects of ions and various kinds of complex biological chemicals may hold keys to the understanding of the overall nervous system in ways that have not yet even entered the concepts of those who are attempting such an understanding. On the other hand, it is also possible that the present view that electric signals constitute the relevant language of nervous systems is largely correct. All Harmon does is to warn that at present there is no way of knowing, that the case has not been proved one way or another.



Thus, there are serious questions, raised by all the participants in this session, as to whether or not brain investigators yet have the appropriate concepts and the appropriate tools. To what kinds of events must such tools and concepts apply? It is now very clear that in the nervous system there is a great deal of parallel information processing going on, which must be measured against the fact that the best scientific understanding to date is primarily of serial digital machines. Harmon points out that it is now quite clear that neurophysiologists are confronted with both discrete *and* continuous processes welded together in single neurons. In computer terminology, a single neuron may be a mixed or hybrid system, a kind of microcomputer in itself, operating in parallel with large numbers of other neurons. Nor, says Harmon, does this necessarily mean that it operates in parallel as a statistical ensemble, of which it might be possible or useful to take some form of average measurement. Rather, these multineuron systems may cooperate in a nonhomogeneous, highly articulate, very complex way. If this is so, and Harmon says that he for one is convinced that in the central nervous system it must be so, then the horizon of problems grows immeasurably wide. We have yet to measure, he points out, the simultaneous action of just a few simple units whose interconnections are well known; in the case of the human nervous system, neurophysiologists are talking about 10^{10} of them. Thus, it is extremely important (although other, liberating concepts have not emerged) to maintain the awareness that present concepts, caught as they are in the computer-idea mold, may be blinding.

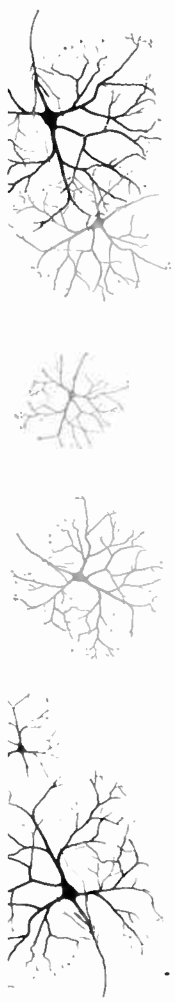
What is meant by 'to understand'?

Nevertheless, the brain–computer analogy is still a useful one, and Harmon turns it to good account in touching on the problem of understanding. There are many levels, he says, at which you can describe a system and on which you can base your understanding of it. He offers a parable of a desert island on which there is a working, high-speed, general-purpose digital computer, complete with its input/output gear, and to the island he imports a number of analysts who have no a priori knowledge of computers, computing, or computability. Their task is to "understand" the machine in three different ways. One group is to find out how to operate the machine, to discover its overall function, its black box input/output properties at the grossest level; their understanding might be demonstrated by their writing of a complete programming manual for the system.

A second group is to discover the principles by which the machine functions, what adders are, how a shift register operates, the function of the remnant magnetism of its ferrite cores, etc.; their understanding might be demonstrated by their designing the flow chart for another, not identical, computing system.

A third group is to find out how the basic components work, how transistors work, etc.; and they would produce highly detailed equivalent circuit analyses.

The point that Harmon makes is that although there are observable relationships among the several levels, it is possible to give a self-contained and adequate description at each level. Each description serves a different purpose. Thus, in seeking understanding, one must stipulate the kind of understanding required in terms of an intention or purpose. Another way of saying this is that understanding is not context-free.



Analogous problems exist in the analysis of living systems. The first group in Harmon's parable corresponds to behaviorists such as psychophysicists and psychologists. The second group is comparable to the neurophysiologists who study information coding, flow, and processing. The third group corresponds to the membrane physiologists and neurochemists.

That there are many possible levels of description in life systems makes for great difficulty, especially in communication among different investigators. Harmon states that even among biologists, and not necessarily only in interdisciplinary discourse, it sometimes happens that the dialogue about understanding goes on at different levels without the participants realizing that this is what is happening.

That there are such serious epistemological and semantic problems implicit in their endeavors to understand the brain rang out clearly throughout the session. Each of the eight participants raised, in one form or another, questions about the understanding of understanding.

All agreed that the analogies between brains and computers that are commonly made are, indeed, ill-taken. As far as is now known, brains and computers—in organization, in purpose, in function, in element, in system—are vastly different.

Such issues, then, which were broadly delineated by Harmon in his introductory remarks, were reverberated in different ways by all of the participants. In addition, each clarified certain levels and aspects of the problems confronting brain investigation today. Though the speakers did not, in terms of the present literature, add so much that was new, what they did was to strike a strong consensus on the difficulties, the complexities, the lack of present understanding, and, especially, the need for new concepts. The deepest question, from which they and their audience could not escape, was this: How much understanding can we hope for?

Coding and use of information in nervous systems

The first contributor, Dr. Leo E. Lipetz, chairman of the Academic Faculty of Biophysics at Ohio State University, is an engineer who gravitated to doing "wet" neurophysiology. He has been influential in studies of frog's vision, and has done work on glial cell interactions. Glial cells (literally "glue" cells), once thought to constitute largely structural support material, are increasingly regarded as performing more important roles in nervous action. In the cortex, or suface level of the brain, there are, in fact, ten glial cells for every neuron. Lipetz's major current work is concerned with questions of nervous system functioning upon the basis of computer and engineering concepts.

Although, in the context of the session, Dr. Lipetz was constrained to be relatively brief, his formal paper presents a thoroughgoing review of the chief uses made of information by organisms.* It discusses typical systems found in organisms to collect, select, and distribute information for such uses; it raises questions concerning the principles of information coding, flow, and use; and it asks about the ways in which neurons are caused to make the proper connections to form these information processing systems. Dr. Lipetz is thus really looking at structures and events in what might be called the "surface" of the organism, the sensory transduction end. That is, he is asking what is known about how the signals from the external world get into the organism. Although he did not specifically address himself to the inverse and equally important problem of information flow outwards (those nervous signals governing the muscular outputs of the organism), Lipetz's theme really centers on the mechanisms involved in the two-directional information flow through the surface of the living organism.

The relation between input information and output action, or between stimulus and response, is determined by the structure of the nervous system. So, Lipetz argues, the existing structure of the nervous system *is* its memory. Learning, which means a change in stimulus–response relations, is the process of changing the structure of the nervous system.

Lipetz summarizes five types of information that the nervous system carries. The first type is information calling for rapid decision and actions. Second is information specifying modifications of the nervous system, including information specifying provisional, exploratory and developmental modification of the nervous system. Third is information specifying which of the modifications tested should be retained. Fourth is information specifying the priorities of the subgoals to be obtained by the organism. Fifth is maintenance monitoring of the central nervous system; this includes override control of the energy and material flows needed for running the nervous system.

The first requirement of an organism, Lipetz says, is that it must receive information about its environment.

* The paper, which will be available (see note on page 58), examines in detail the known kinds of nerve cells and their known functions. Our excerpts are merely meant to suggest what is known and not known.

In physical terms, this information must be collected by the interaction of atoms or molecules or quanta of radiation from the environment with molecules or atoms of the organism. The input to the organism's surface is enormous. For instance, a person sitting in a well-lighted room receives on every square centimeter of his exposed skin about 10^{14} photons every second from the environment. That exposed skin is also being hit by about 10^{25} molecules per second on every square centimeter. If every one of these collisions were to be reported to the organism the result would be chaos. Therefore, the *primary function* of the information-collecting devices of an organism is to throw away almost all the information regarding the environment–organism interface and retain or select only that information highly relevant to the survival of the organism.

Those cells of the organism, Lipetz continues, whose function is to collect information about the interface between organism and environment, and pass this information on to other cells, are known as *sensory receptor cells*. These cells act as *transducers*; they change the form of energy with which the environment acts on them to another form of energy that can be transmitted to other cells. These cells also amplify the energy involved, using energy sources from within the cell and the organism.

The mechanisms involved in these processes are, in themselves, immensely complex; Lipetz summarized what is now understood about them. But what is not known now is how the central nervous system works. The fact is that precious little is yet known or understood about its complex, integrative details. To use a loose computer analogy, neurophysiologists have begun to learn a little about the I/O (input–output) gear, but they still must get to the central processor.

Brains and computers: elements to systems

Following Lipetz in the formal session was Dr. E. R. Lewis of the Electrical Engineering and Computer Sciences Department of the University of California, Berkeley. He took up the subject of the relationships of elements to systems in brains and computers. An electrical engineer by training, he has worked on membrane modeling, and now is about to "go wet" by doing direct neurophysiological experimentation as well.

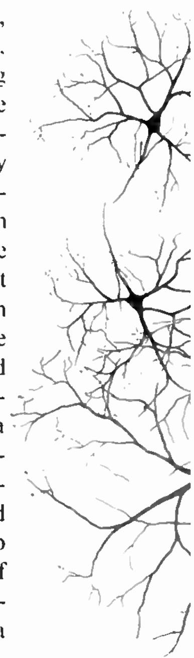
His major contribution so far has been to develop what is considered to be the finest of all neural models that are based on membrane mechanics. These models are very sophisticated, electronic, real-time hardware analogs of the Hodgkin–Huxley model of nervous tissue. Lewis' work shows primarily how, with a very few parametric variables, one can get a very large number of heretofore not well-understood phenomena that Hodgkin and Huxley had *implicit* in their analyses, but which no one had demonstrated explicitly. Lewis has elucidated with his models several important membrane mechanics functions that had long been mysteries.

Lewis begins with what amounts to an exclamation. No sensible engineer, he says, would attempt to describe the operation of a digital computer in terms of the solid-state physics of its devices, or even in terms of highly abstracted equivalent circuits for each device. How then can physiologists expect to understand the brain in terms of highly abstracted properties of neurons, let alone membrane biophysics?

If *understanding* is his goal, Lewis argues, he has the added burdens of selecting the level of understanding he wishes to attain and the course that he believes will lead most expeditiously to that level. The difficulty of the second choice probably depends strongly on the first choice. If one wished to understand the processing of electric signals by nerve-cell membranes, for example, the choice of courses open to him might be fairly obvious. He might decide that the most expeditious of these courses would be to join the legions of investigators measuring voltage–current characteristics of the squid's giant axon (which has one of the most widely studied membranes) and to attempt to describe and generalize the results in terms of irreversible thermodynamics.

There is a good chance, Lewis says, that in the near future we shall understand reasonably well the physical mechanisms underlying the operation of the membrane of the largest of the squid stellate axons. We shall then be left with the enormous question of whether or not these results are applicable to other neuronal membranes.

Lewis continues: If one wished to understand the processing of signals not by a patch of membrane, but by a whole neuron, he might wait until the final squid-axon results have been posted, then attempt to extend them to a distributed system of dendrites, soma (cell body), and axon. If the electrical properties of the squid-axon membrane resulted from local changes of state of bound water, or from configurational changes of protein molecules, he might attempt to describe neuronal signal processing in terms of coupling of these changes over the entire spatially distributed neuron. Since engineers are designers rather than observers, the electronic devices they employ normally either are lumped or are spatially distributed in an easily describable manner. No problem from electron device physics really is analogous to the problem of the neuron; thus comparisons are difficult to make. Actually, the neuron probably is very much like a many-branched, lossy transmission line, some branches being active, some branches being passive, and some branches containing more or less discrete, time-varying (synaptic) elements. Thus, although it is a spatially distributed entity, the neuron more closely resembles a network of devices than a single device. Describing it in terms of coupled state changes of bound water, etc., would be somewhat analogous, therefore, to describing a complicated electronic circuit in terms of Fermi levels, conduction bands, electron–phonon collisions, mean-free paths of electrons, etc. Would such a description be conducive to "understanding" the operation of the circuit? Perhaps it would be, Lewis says, but most engineers would be quite satisfied with a more simplified description, one in terms of wires, ohmic resistors, linear capacitors, linear amplifiers, and switches.



Even though engineers were the *designers* of its elements, he goes on, they nonetheless chose to describe the circuit in simplified (idealized) terms. Being not designers, but merely observers, neuroscientists might be justified in not being more ambitious. Analyzing the neuron as a distributed system of ohmic conductances, linear capacitances, time-varying elements, and active elements has proved to be a sufficiently enormous task even without the complications of considering underlying physical and chemical mechanisms. So far, in fact, even the partially successful analyses have not included the distributed aspect and have treated the neuron as a system of lumped elements.

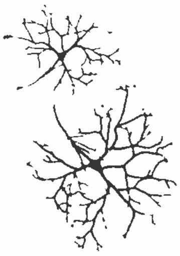
Rather than being concerned with signal processing in single neurons, one might wish to understand the operations of various small networks of neurons. Lewis asks: What course should he choose? Should he attempt to describe such a network in terms of coupled state changes in bound water (or whatever else is dictated by the final verdicts from the squid axon)? Should he describe it as a system of systems of distributed (or lumped) conductances, capacitances, time-varying elements, and active elements? Or should he attempt to find a simpler description? Perhaps he could abstract the properties of each neuron to the extent that it becomes describable as a simple system element, with known terminal variables and describable relationships among them. Can he be satisfied that he "understands" a small neural network if he can describe its operation in terms of such abstract neurons? What about large neural networks; what about the brain?

At this stage in his line of reasoning, Lewis cites a nine-cell system illustrating the magnitude of the difficulties. In many animals, including crabs, lobsters, and shrimps, the heart is driven by the output signals from a small group of neurons known as the cardiac ganglion. This ganglion makes afferent and efferent connections to a complete effector (the heart). Although its behavior can be modified by certain extrinsic neural signals, it is nonetheless essentially autonomous; its neurons are interconnected synaptically and electrically; and it is spontaneously active, exhibiting integrative and patterned activity. It is thus essentially a complete nervous system in itself, with properties very much resembling those of much larger nervous systems.

It was such a system—a single cardiac ganglion from the lobster, consisting of nine interconnected neurons (i.e., one functional unit)—that was the subject of a concerted effort at understanding its operation. The particular ganglion studied produces periodic bursts of impulses at a rate of approximately one burst per second. The goal of this intensive physiological study was clearly defined from the outset: to determine how the ganglion generates those bursts. Physiologists employed virtually every type of experimental technique available for nervous systems, small or large. The ganglion was studied in place on the inner, dorsal wall of the heart, and removed from the heart. Efforts included behavioral and pharmacological studies, systematic ablation (surgical removal), gross electrophysiological and microelectrophysiological measurements, statistical measurements and analyses, intensive histological studies, voltage-clamp and current-clamp experiments, and intensive neural modeling. In short, the repertoire of experimental and theoretical neurological techniques has been almost exhausted. Although the lobster cardiac ganglion is by far the most thoroughly studied and best understood ganglion of comparable size, it is not yet understood as a *circuit*.

If this intensive study of a nine-cell system is to stand as a model for the future, what is to be expected of studies of the brain, which contains ten billion neurons? Although understanding the brain is sufficiently difficult in itself, the difficulties may very well be compounded by the general insistence on understanding it as a circuit.

Circuit analysis, Lewis noted, typically deals with unoriented objects, which have terminal variables but which are without specified causal relationships. A resistor, a



typical circuit element, has two variables (current and voltage) at each terminal, but who can say, Lewis argues, which variable is cause and which is effect, or which terminal is input and which is output? Formal systems theory, however, typically deals with oriented objects, objects with specified inputs, specified outputs, and specified causal relationships. Presently, people seem much better able to understand systems of oriented objects than circuits of unoriented objects. In fact, an engineer almost always must reduce a circuit to a system or system element before he can say he understands it; and he almost always designs a circuit to meet specifications for an oriented system element. He would analyze and understand a computer, for example, not as a circuit of resistors, diodes, capacitors, magnetic cores, etc., but as a system of clocks, scalers, storage bins, and so on.

In the final analysis, Lewis concluded, it may be impossible to describe the brain as a system of oriented objects. It may in fact represent more of a circuit problem than a system problem. But until we know that it does, why should we assume the worst? Why not, he asked, treat the brain as a system rather than a circuit? Why should we try to do something with the brain that we don't even do with systems of our own design? Thus, Lewis concludes, if the brain investigator identifies an oriented object, identifies its terminal variables, and finds descriptions for relationships among the variables, he does not need to learn anything more about the object in order to understand the system. He does not need to know the biophysics or the biochemistry or the circuit interactions that underlie the operation of the object, any more than the computer designer needs to know the impurity profiles of the semiconductors in his ring counters.

In a sense, Lewis is pointing out that whereas it is probably hopeless to treat the brain from the single-neuron level, it may be hopeful to go higher in level. Lewis is specifically proposing that the circuit approach be replaced by the system approach.

Images of the brain

In the last paper, "Images and Models of the Brain," Dr. Peter Greene of the University of Chicago Committee on Mathematical Biology discussed aspects of systems organization in computers and brains. He stressed a model of an organismic control system in which executive commands triggered subroutines, which work out their local problems in an *ad hoc* way, using whatever stored sequences of operations correspond closely enough with the needs of the central or executive command. Greene, who is primarily a mathematician, has done extensive work on mathematical descriptions of theoretical models of nervous action at the systemic level.

Although Greene did not go into detail on the mathematical formulation of this kind of *ad hoc* control system, his following somewhat intuitive images should convey the flavor of the kind of system he is considering.

He begins: Write by holding your pen still and moving the paper instead with your other hand. You can do it, although you have never done it before. You are somehow doing the "same thing" with different muscles that move differently and require different signals from your brain.

Your brain could never store recipes for performing *every* variant of *every* action by *every* different set of muscles. So how does an action "get into" a particular set of muscles? How could a robot guide complex linkages to perform skilled actions?

When a cat turns its head to follow a mouse, the act of turning will tune movement control centers in such a way that, at any time, the brain has only to decide, "Jump!"—and the jump will be in the right direction, because all has been prepared beforehand by reflexes. The cat's brain is like a general who commands, "Take Hill 7!" A general does not have to know the details. Provided with officers who know how to modify these plans to fit particular conditions, and when to switch from one plan to another, the general has only to select from a small set of overall tactics.

Many activities of animals and of the most interesting computer programs and machines follow the above scheme, which can be very subtle. For instance, a low-level plan might, at any time, be replaced by another, if the two happen to coincide throughout some range of conditions surrounding the existing conditions, or be replaced by a third plan that differs from either but can be used because somewhere there is an adjustment that compensates for the difference. Since even the basic plans differ from time to time, muscle to muscle, and person to person, one may wonder how to search for any uniform scheme to organize this fluid situation, to get the "same action" from different muscle groups, and to recombine the same movements into different acts.

Finally, Greene says, customary mathematical studies of control systems fail to address these aspects.

The panel discussion

The first panel speaker was Dr. J. H. Bigelow of the Institute for Advanced Study, Princeton. Dr. Bigelow is a very noted engineer-mathematician, who was the chief engineer for von Neumann's famous first stored-program digital computer, and who is credited with bringing many of the early concepts of cybernetics to bear in the machine field.

Dr. Bigelow quietly opened his remarks by duly noting the enormous complexity of the neuroanatomy of the brain of any living animal. Both at the level of the manifest structural element—the nerve cell—and at the level of assemblies of such elements forming recognizable organs in the animal, he said, one can point to complexity that is (beyond argument) greater (by many powers of ten) than any physical system man can claim to "understand" today. This means that attempting to "understand" every detail of "how the brain works" is, for the foreseeable future, hopeless. This does not, however, imply that the goal of understanding much more—perhaps a hundred or thousand times more—than what we now know is hopeless. Quite the contrary.

There are, Bigelow went on, certain implications regarding feasible ways to proceed along the path toward better understanding of the brain. He stated his belief that a purely theoretical approach—using mathematics, logic, etc., and *solely* the tools of pencil, paper, digital computer, plus human intellect—is doomed to failure and perhaps to an even worse fate, akin to a cancerous proliferation of mathematical artifacts, such as model systems distinguishable only up to equivalence classes. Furthermore, a *purely* experimental approach, using anatomical, cytological, pharmacological, electrophysiological tools on authentic living animals and tissue samples is an avenue also doomed to inadequate progress or failure by exhaustion of the experimentalist's ability.

Bigelow continued: I believe that to achieve the progress that ought to be possible in the immediate future will require intimate cooperation between mathematical and physical scientists and biological scientists directly engaged in experimentation upon living systems. Only in this way can worthwhile experiments be formulated and performed upon authentic biosystems. Such experiments should be, above all, aimed at critical proof or disproof of the hypothesized role of certain biological subsystems (e.g., the nerve cell and its synapse, etc.). The goal should be to solidify step by step some network of hypotheses woven into a description of the gross observable behavior of the animal.

As an example of the essential need for close interaction between physical scientists and biological scientists, Bigelow chose the problem of cellular form and function and the supposed taxonomic and behavioral specificity of the nerve cell. What is needed, he stated, is a less rigid characterization of the cell as a building block than either bio- or physicoscientists would seem to prefer. In particular, there is the ancient mystique within the biological sciences that "form implies function" and this clearly needs to be re-examined.

Finally, Bigelow said, there are many other directions along which the problem of understanding brains may be approached, if collaborative effort between experimentalists and schematists can effectively be brought to bear. Among others, he listed the following: (1) invariance of observed performance under disabling intervention (drugs, ablation, etc.) of neural subsystems; (2) apparent distributivity of aspects of "memory" and "learning"; (3) the address-free aspects of central nervous system function; (4) "addressable" learning and behavioral modifications phenomena (via "conscious" pathways); (5) the neural "set intersection centers" of this living organism (i.e., ganglia, etc.); (6) the state of theoretical understanding of certain necessary and sufficient conditions for pattern recognition; and (7) the state of knowledge of the effects of certain pathologies, chemical effects, etc., on the terminal behavior of the living system.

In the conclusion to his remarks, Dr. Bigelow seemed to be reacting in part to the generally negative tenor that had characterized the session and he seemed to be warning the younger investigators. I would say, he wound up, that it is easier for people in 1968 to underestimate what has been contributed and to be overly pessimistic about what the tools of modern information science can do, than in the past. In effect, he was saying that the seemingly hopeless complications do not constitute a reason for being discouraged about the future.

Computer–brain contrasts

The panelist who stuck most closely to one of the original questions on the relationships of brains and computers was R. W. Hamming of the Bell Telephone Laboratories. Known for the "Hamming distance," and for error-correcting codes, his primary contributions have been in numerical analyses, which have led him into questions regarding computer functions and, in turn, to brain functions.

In making his man–machine comparisons, Hamming is really drawing a series of compelling contrasts that do not pretend to have scientific import so much as to throw a refreshing look at what has become a socially entrenched cliché. Hamming begins by noting that people often and somewhat carelessly suppose that the modern electronic digital computer provides a model for the human nervous system. For example, he said, they often equate the computer storage with the human memory, the central processer of the computer with the human brain, machine learning with human learning, and so forth. But other comparisons between solutions that man and nature have found for similar situations (e.g., wheels versus legs, flapping versus rigid wings, muscular contraction versus burning fuel) show radically different solutions.

In that light, Hamming said, it is rather strange that people expect to find close analogies when we come to the fields of information transmission and processing. For one thing, the raw materials in information transmission are staggeringly different. For another, the velocities of the propagation of signals are orders of magnitude apart. The human nervous system has velocities of from one half to a little more than 110 meters per second whereas computers send signals up to 3×10^8 meters per second. Again, man has available a wide range of electronic amplifiers whereas nature seems to have confined herself to relatively slow electrochemical measures. Man has used for information representation rather straightforward examples of analog signals, amplitude modulation, frequency modulation, phase modulation, delta modulation, pulse code modulation, and so on. Nature, as far as we know, seems to be using some mixed combinations that no engineer in his right mind would use.

The purposes behind the design of computers and humans are fundamentally different. Man has designed his computing machines so that the storage can be completely erased and the machine started afresh. Our software systems are designed so that there is a minimal amount of communication when we pass from one problem to the next. We want our machines to do exactly what we say, to do it again and again with incredible faithfulness and reliability. Nature, however, seems to have designed man to have a good deal of variability, as well as a memory of past experiences, so that he can profit from what may at first appear to be independent experiences.

Again, we are prepared to halt a machine completely for preventive maintenance, repairs, and alterations; nature's equivalent is, apparently, sleep, in which the central nervous system activity, although still present, operates in a significantly different fashion from that of the normal waking state.

With such great differences in the materials used, in the forms of representation, and in the signals used for transmission, as well as in the fundamental premise of the basic design, it seems rather unlikely that close analogies in the structures will be found between man and machine, except by pure chance.

The analogy between how men solve problems in their minds and on computers likewise does not seem to be a good one. Currently available machines use numbers and discrete symbols in an essentially sequential manner, whereas humans have powerful Gestalt, parallel, pattern recognition powers of which we have at the moment almost no understanding.

In summary, Hamming said, it does not seem that present-day computers are significantly more closely related to the study of the human nervous system than they are to many other branches of knowledge. Computers will be very useful in modeling, in simulating, and in calculating, just as they are in other fields, but the hope that present-day computers will especially reveal the fundamentals of the human nervous system seems to be unreasonable, although not impossible.

To be positive

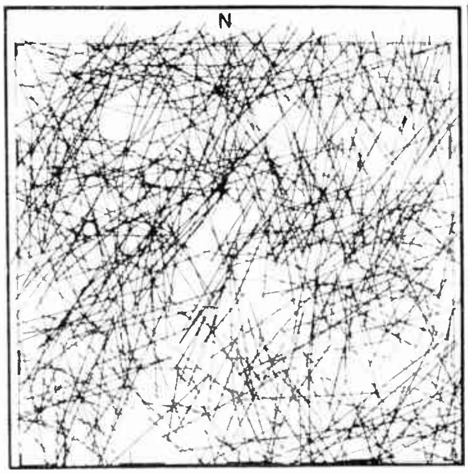
With the third panelist, Oliver Selfridge of the M.I.T. Lincoln Laboratory, the discussion took a new turn. Well known for his pioneering work in pattern recognition and in machine simulation of certain aspects of intelligence, Selfridge is perhaps as well known for his verbal and critical facilities. In this case, he pleaded in rapid-fire fashion against the negativism evidenced during the discussions.

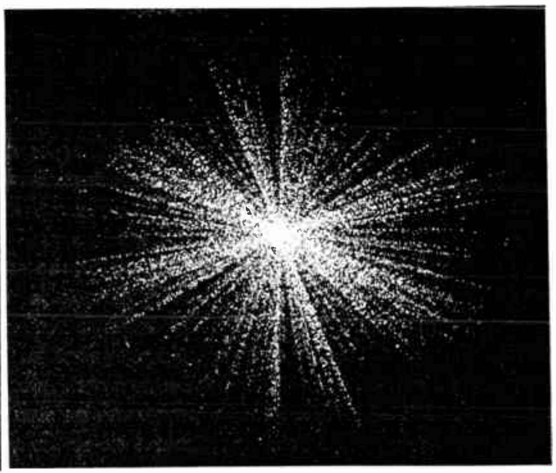
Although we don't have much knowledge, he said, we do have a lot more understanding than we had before, as, for instance, in the work of Lettvin and Hartline. Lettvin happily chose the frog's eye, because the understanding that came from that paper of his about what the frog's eye tells the frog's brain is just great. That is, he asked the right questions.

Lettvin's work, E. R. Lewis notes, is a good example of the system approach, since Lettvin did not try a circuit analysis of any sort. Lewis further notes that Lettvin chose the frog's eye because he knew it was an oriented object. His major contribution was in his choice of input variables, namely, in his choice of visual patterns appropriate to frog behavior. In this respect, he "asked the right questions." Others that Selfridge and Lewis might have cited as having successfully applied the systems approach include Roeder, Reichardt, and Mittelstaedt.

Last man on the panel was Dr. V. A. Vyssotsky of Bell Telephone Laboratories, Whippany, N.J., who is head of the basic software department there, and who has worked primarily as a mathematician in the investigation of new software computer systems of great complexity and reach. A distillation of Vyssotsky's two major points might go as follows: We don't understand enough about the nervous system to make useful theoretical models except in a few small areas (e.g., chemistry of neural membranes); therefore, neurophysiologists should gather as much real descriptive data as possible before rushing into theoretical models. We should like to gather data that will be of interest to chemists, biochemists, electrical engineers, and computer people, he added, in the hope that it will stimulate them to formulate their advances in a way that we can then build upon.

The complete papers of the session "To Understand Brains . . . " will be published as a book by Prentice-Hall early in 1969.





FRACTURE pattern traced from aerial photograph (left) and its optical transform (right).

Optical processing in the earth sciences

This review of how optical processing has been applied effectively in the earth and space sciences shows that information in pictorial form may be best handled by optical data-handling systems

M. B. Dobrin *United Geophysical Corporation*

Optical processing of information has been understood in principle for nearly a century, but it has found little practical use thus far except in the earth and space sciences. This article describes briefly the advantages and principles of optical data processing through transformation and frequency filtering, and gives some elementary examples of the handling of pictorial information in the fields of oil prospecting, spacecraft photography, and weather satellites. Substantial advances in the capability of optical systems for handling such information are foreseen.

Of all the techniques now in use for the handling of information, optical processing is the oldest from the standpoint of coverage in the literature and the newest from the standpoint of practical use. It has been almost a century since Ernst Abbe[1] published a classic paper demonstrating how information on a picture can be filtered by forming a diffraction pattern and by blocking appropriate portions of the light in the pattern. He showed that this is possible because the diffraction pattern is the two-dimensional Fourier transform of the light distribution in the picture. Over the past 15 years, a number of authors such as Maréchal and Croce,[2] Cutrona,[3] and O'Neill[4] have shown how Abbe's concept could be related to modern information processing principles that are applied in the design of electronic filter systems. But it was not until the gas laser was introduced in the early 1960s that it became feasible to use optical methods for processing data on a routine production basis.

In contrast to electrical analog and digital processing, the extent to which optical data-handling systems are being employed is quite limited. The primary advantages of optical techniques over the other two are best realized when the information to be processed has two degrees of freedom. A picture, for example, has two independent variables (the x and y position coordinates) and one dependent variable (the density at the position specified). Optical systems correspondingly have two degrees of freedom; thus, for handling pictorial data, they are intrinsically superior to electrical or electronic systems, which have only time as an independent variable.

Although there are many potential applications for optical filtering systems where information of this type is

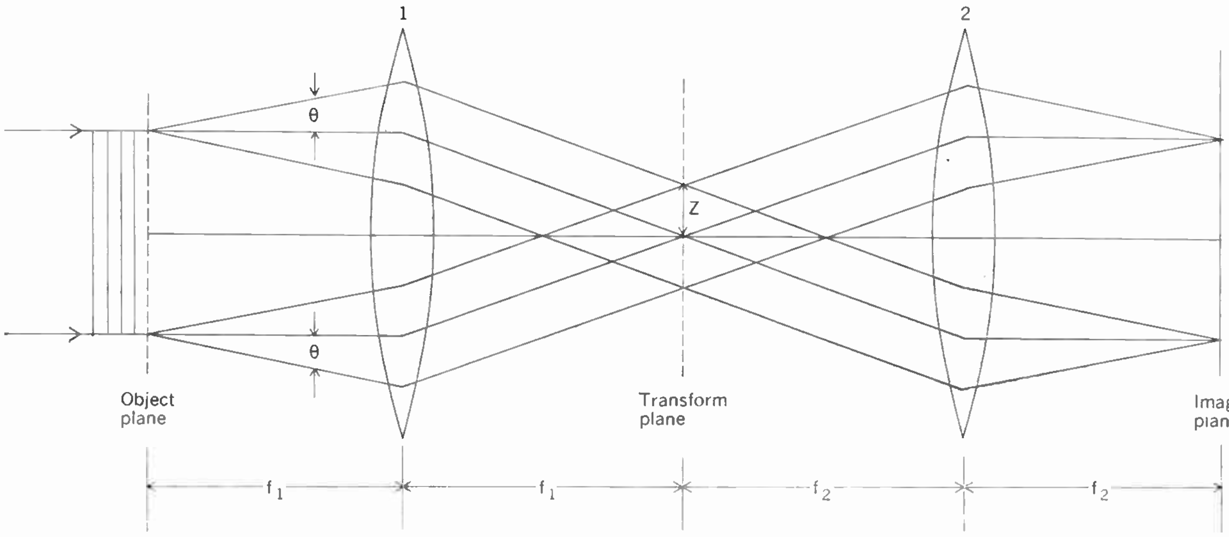


FIGURE 1. Optical system for filtering pictorial information by forming a Fraunhofer diffraction pattern.

involved, their greatest commerical use up to now has been in the handling of resource and environmental data from the earth and its surrounding space. The entire subject of optical processing is thus quite appropriate for any group concerned with the acquisition, interpretation, and utilization of such data.

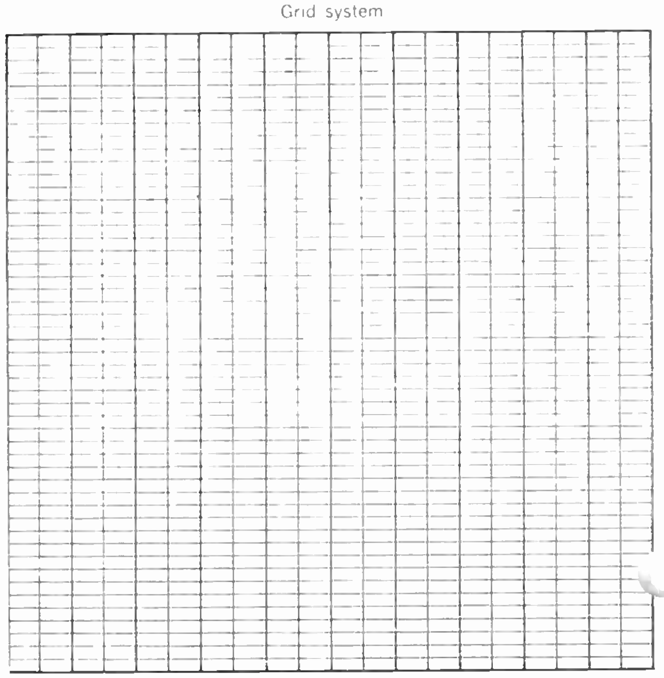
The earliest commercial application of optical data processing was to the analysis and filtering of seismic records obtained in the geophysical exploration for oil.[5,6] Even now, so far as can be ascertained, this constitutes the most widespread single use of optical processing techniques. Numerous other applications to the study of the earth, although not yet commercially exploited on any large scale, have been developed; some are described in this article.

Principles and instrumentation

The relationship between the Fraunhofer diffraction pattern of a two-dimensional light amplitude distribution and the Fourier transform of the distribution function is illustrated in Fig. 1. If the information to be processed is transferred to film and if a beam of coherent light, such as from a laser, is passed through it, a lens situated a focal length beyond the film transparency will convert the information into a diffraction pattern that, as Abbe showed, has all the properties of the Fourier transform of the input information. Another lens beyond the transform plane a distance equal to its own focal length will convert the diffraction pattern into a second Fourier transform. But as the transform of a transform of a function is the original function itself, the final image, or reconstruction, is the same as the original input reduced or enlarged by a magnification factor. If one blocks the light focused in those portions of the transform plane corresponding to undesired spatial frequencies or directions of orientation, the final image will then show all the information on the original input except for that which has been removed in the transform plane. This phenomenon is the basis for optical filtering.

The transform itself presents the input information in a form that is exceptionally convenient for frequency analysis; it is a simple matter to photograph it for this purpose. If the density distribution on the original picture is looked upon as the two-dimensional function $F(x, y)$, the transform, as shown by Born and Wolf,[7] is the corresponding two-dimensional function $U(\omega_x, \omega_y)$ of the spatial frequencies in the x and y directions. Because photographic film responds to the square of the light intensity and because the phase term of the transform cannot be preserved on the photograph without the introduction of a reference beam like that in holography, the transform becomes the two-dimensional power spectrum of the information in the output. In other words,

FIGURE 2. Transform pattern (at right) for two series of parallel lines perpendicular to each other.



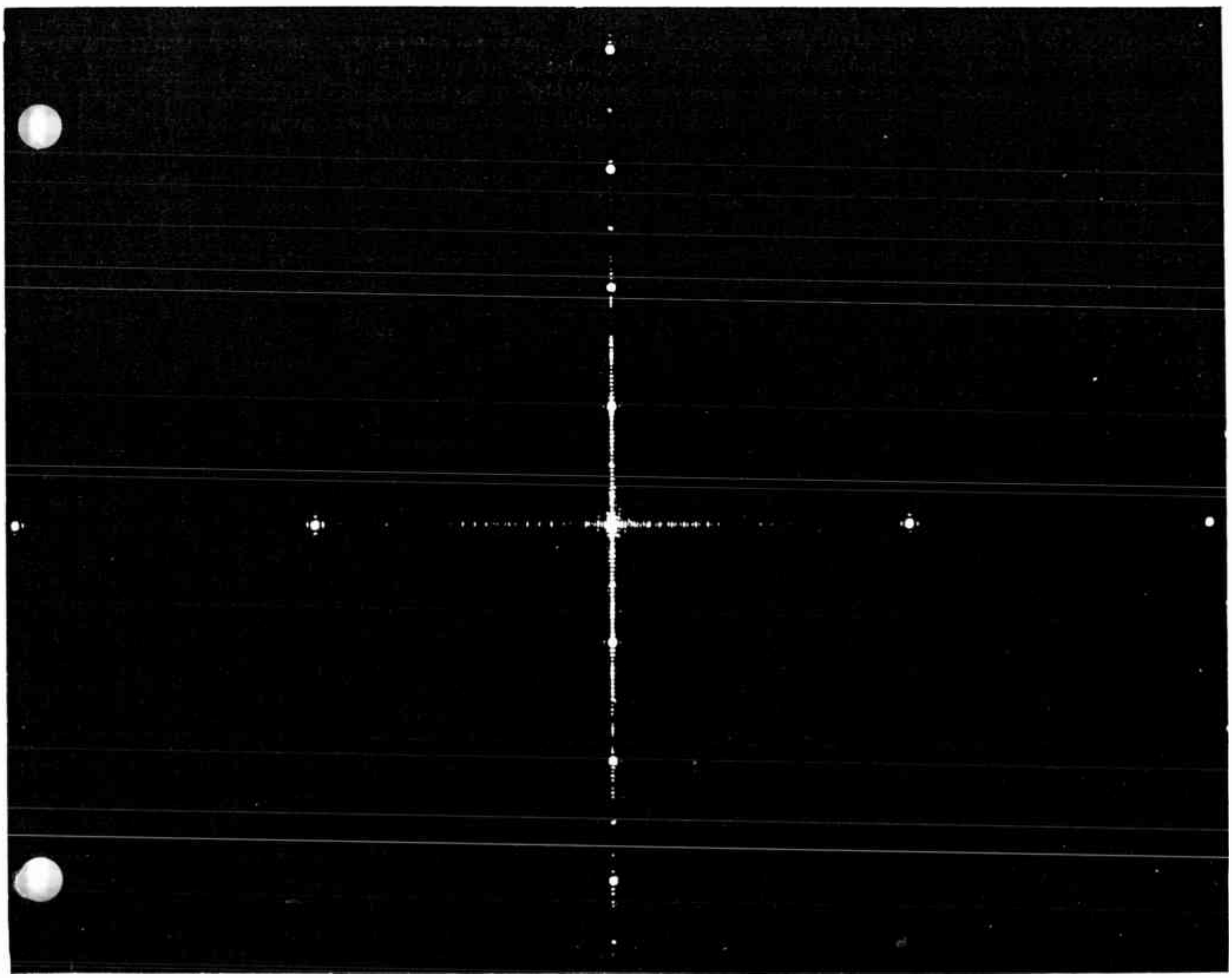
the amplitude term is recorded but not the phase.

Figure 2 shows the diffraction pattern or transform for two series of equally spaced parallel lines perpendicular to one another, each set having a different line separation. The dots corresponding to the two gratings are along lines through the central axis which are each perpendicular to the respective grating lines. Along the axis there is a spot for the undeflected, or zero-order, light (generally referred to as the d.c.). The two nearest spots to the center along each line are first-order diffractions, and those successively further are second-order, third-order, and higher. The distance of each first-order spot from the central axis, as well as the distances between spots of successive orders, is inversely proportional to the separation (or directly proportional to the spatial frequency) of the lines in the grating. This is evident when one compares the separations of the dots along the respective axes.

All data in pictorial form, no matter how complex, can be looked upon as the synthesis of an infinite number of properly weighted individual grating elements such as these, each with a different spatial frequency and orientation. This is the two-dimensional extension of the Fourier series representation of a simpler one-dimensional function, such as an electric signal, plotted against time. The two-dimensional transform, such as shown in Fig. 3, of an actual picture will normally consist of a cloud or swarm of dots that can no longer be individually resolved. The fact that the transform is elongated in a north–northwest direction is attributable to prominent lineations on the original photograph perpendicular to the axis along which light is concentrated on the transform.

Optical filters consist of opaque disks, annular rings, wedges, or knife edges, which are maintained in their proper position in the filter plane by appropriate positioning devices. Figure 4 shows several basic types of optical filters. For passing high spatial frequencies, an opaque disk is centered along the axis as shown in the upper left. Actually, the disk must have a hole in the center to pass the d.c. or undiffracted light along the axis. Otherwise there will be distortion from frequency doubling in the filtered output. The low-cut frequency limit is determined by the diameter of the disk. To pass only low spatial frequencies, an annular ring of the type shown in the upper right is employed, the inner radius determining the high-cut frequency. For directional rejection, the wedge pair in the lower left removes all lines having orientations within the range of angles perpendicular to those encompassed by the wedge edges. For passing a

Diffraction pattern



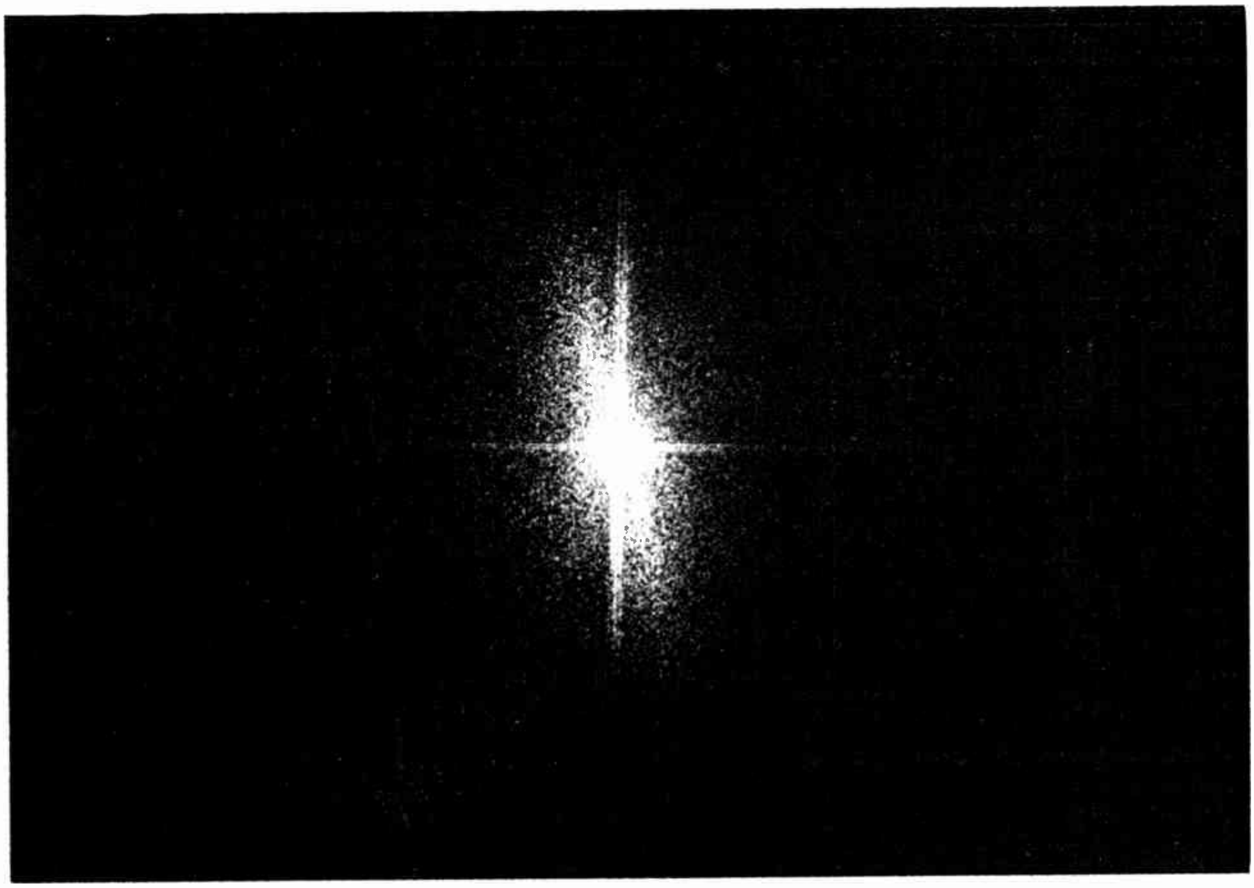
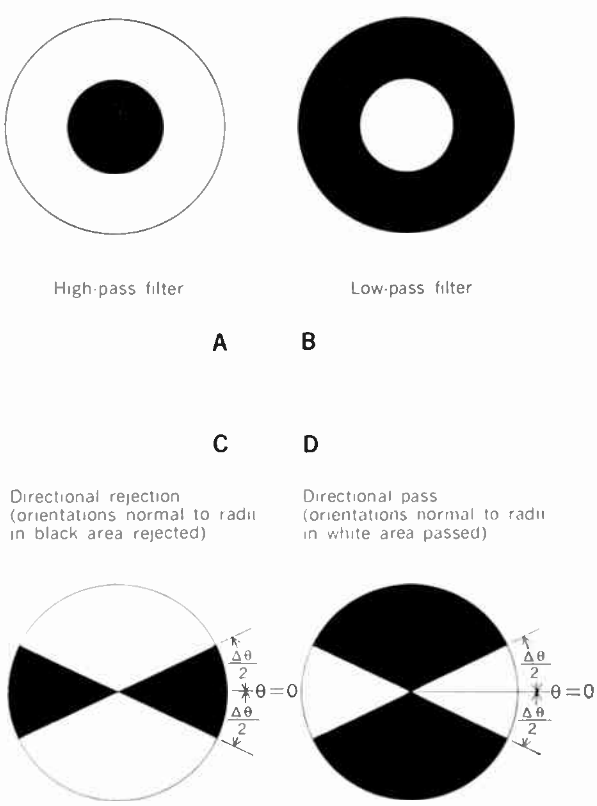


FIGURE 3. Two-dimensional transform of an aerial photograph having prominent lineations in the east–northeast direction.

FIGURE 4. Four types of optical filters. These are inserted in the transform planes.



limited range of directions, wedge-shaped windows are cut in an opaque disk covering the transform plane.

The effectiveness of the frequency filtering can be shown by the way a series of line gratings corresponding to different frequencies can be processed through a bandpass optical filter set to reject all but one of the gratings. For instance, frequencies that are only 6 percent different from the passed frequency can be cut off very sharply by this type of filtering.

A special instrumental system called LaserScan* has been developed for optical analysis and filtering of geophysical and geological data. This instrument is equipped with a television screen that makes it possible to monitor the results of filtering with instantaneous feedback, facilitating the selection of optimum filter parameters by trial and error. This capability in itself gives optical processing one of its greatest advantages over other types of information handling.

Optical processing of seismic data

The most widely used geophysical technique in the exploration for oil is the seismic reflection method. Dynamite charges (or impacts from mechanical sources) are set off near the surface of the earth and the seismic waves thus generated spread out in all directions into the earth. When the waves hit geological boundaries where the rock characteristics change, part of the energy is reflected back to the surface, where it is received by strings of geophones. The signals from these phones are recorded on magnetic

*Trademark Conductron Corporation.

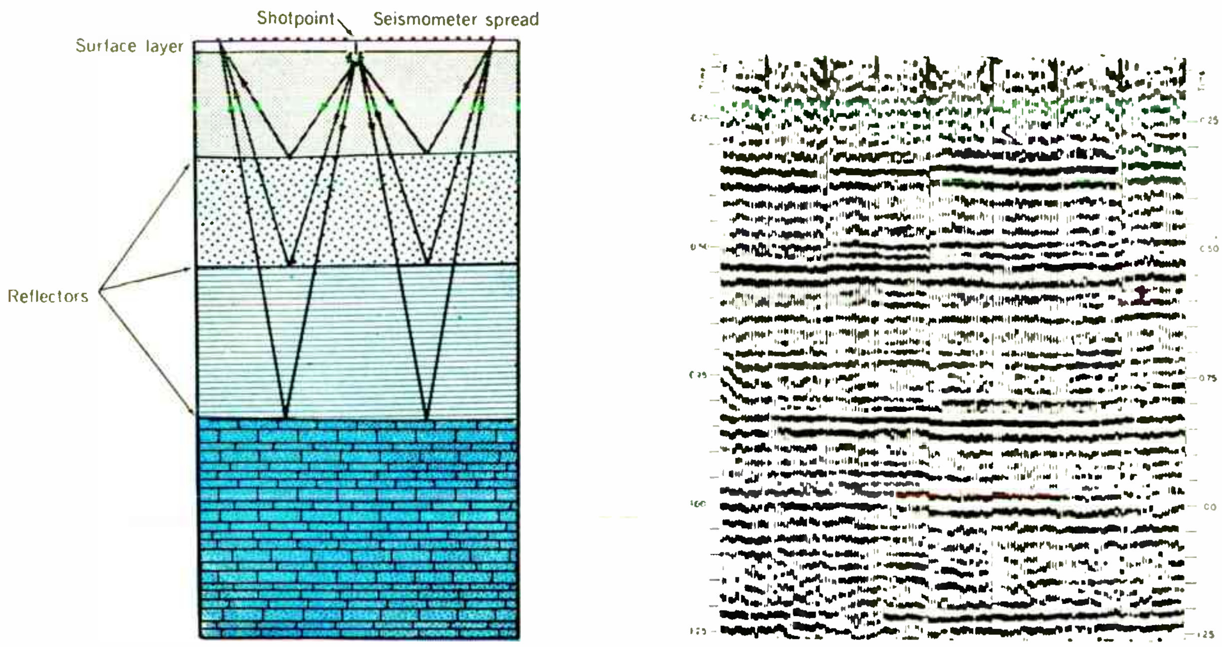
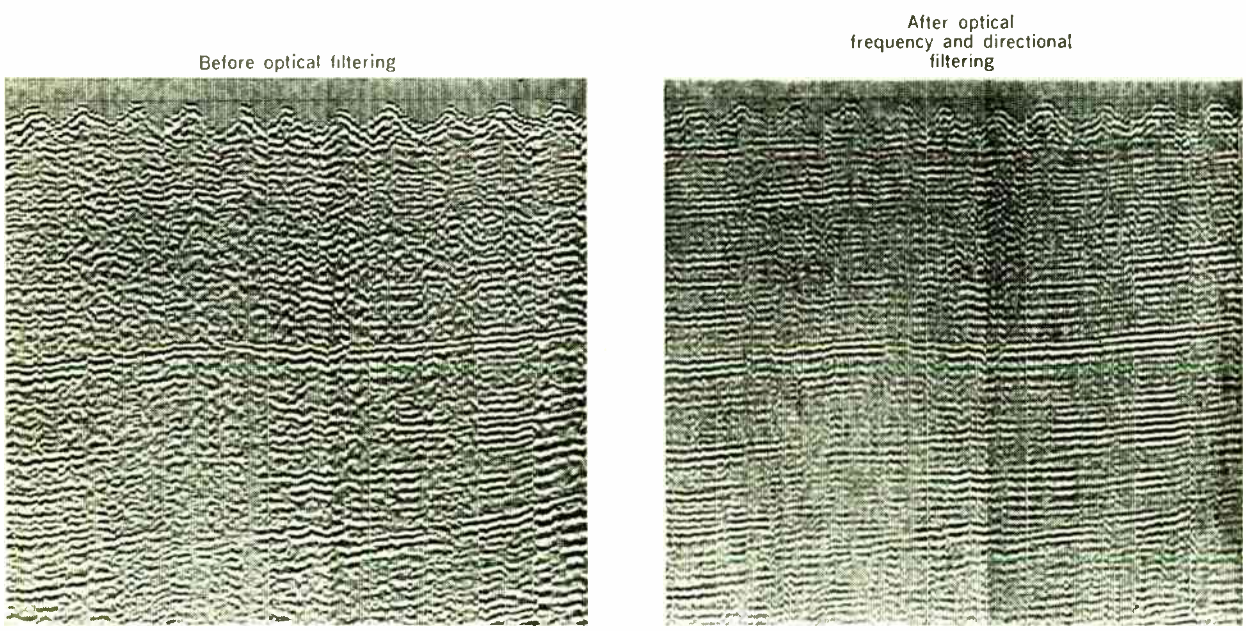


FIGURE 5. Good-quality record section with diagram illustrating corresponding subsurface configuration of beds.

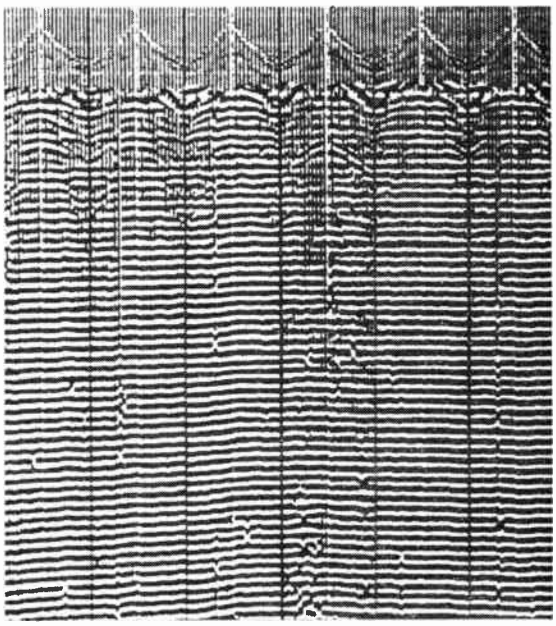
FIGURE 6. Results of optical filtering where original reflection data are hidden by noise. Note particularly the improvement in continuity over the shallow part of the section.



tape, which may be digital or analog, and after playback they are plotted on record sections somewhat similar to geological cross sections of the earth below the shooting profile. These sections show the structural characteristics of the subsurface rocks. Where the structure thus indicated appears favorable for oil accumulation, a drilling location will be selected.

The reflections are identified on the record sections as wave cycles lining up more or less horizontally across many successive traces representing adjacent receiving positions along the surface (see Fig. 5). Much of the time these events are so obscured by noise that they are not distinguishable without special processing. This noise may take several forms. In seismic surveys under marine areas it could be the result of ringing or reverberation of the reflected waves in the water layer. Reflections are almost impossible to follow on such a section. Another source of trouble is scattered noise from near-surface irregularities.

To eliminate noise of these and other types, the most effective approach is generally frequency or directional filtering. Analog, digital, or optical filters may be used.



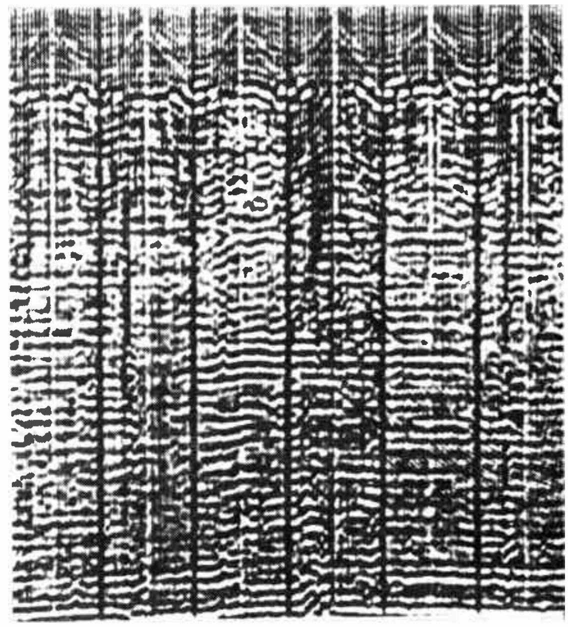
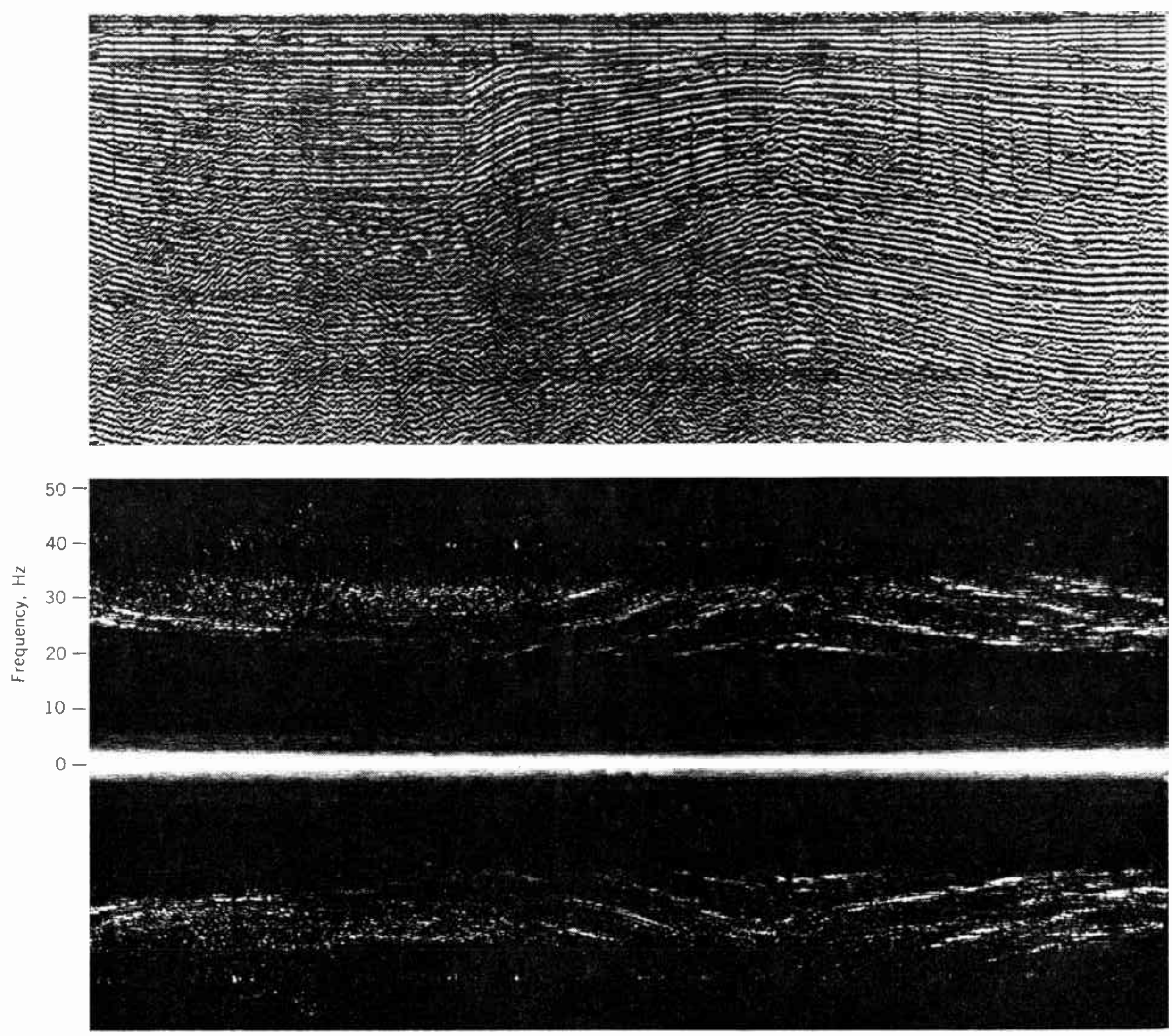


FIGURE 7. Optical filtering of marine section where reflections are obscured by heavy ringing.

FIGURE 8. One-dimensional transform of marine section. Note harmonics of ringing frequency. Changes in ringing frequency shown on transform are related to changes in water depth across the section.



For optical filtering, the section is reduced and printed on 35-mm film. Frequency and directional filtering are carried out simultaneously in separate transform planes, the cutoff values being determined by visual monitoring on the television screen.

One example of such filtering is shown in Fig. 6. Useful reflections are completely hidden by incoherent noise from severe scattering in the near-surface formations. Optical filtering of the frequencies in which the scattered energy is concentrated results in much better definition of reflections across the section.

Figure 7 shows an example of how optical filtering is used to remove ringing from marine records. The left side of Fig. 7 shows a section with so much reverberation in the shallow water layer that reflections are indistinguishable. The ringing events or "zebra stripes" correspond to a strong concentration of the seismic energy at a single frequency associated with the reverberation time of the seismic signal within the water layer. Removing this frequency by a high-cut optical filter leaves the considerably clearer picture of the subsurface structure shown on the right-hand side of the illustration.

The frequency transforms of seismic sections can themselves be very useful for analyzing problems encountered in field recording and for direct interpretation of the data.[8] In studies of this kind the one-dimensional transform is most helpful; the frequency spectrum is shown on a channel-by-channel basis so that one can observe any variations of frequency composition between one part of the profile and another. This type of transform is obtained by substituting a cylindrical lens for the spherical lens shown in Fig. 1. The axis of the cylinder is perpendicular to the channelization.

The one-dimensional transform of the marine section in Fig. 8 shows that the data are subject to heavy reverberation and that there are successive harmonics within the range of seismic frequencies. The frequencies vary from one side of the section to the other with changes in the depth of the water in which the reverberations take place.

Another use of frequency transforms is to locate oil-bearing reefs by subtle changes in frequency associated with thinning of beds by compaction over the reef masses. The reefs often show up more clearly from anomalies on the transform than they do on the original section.

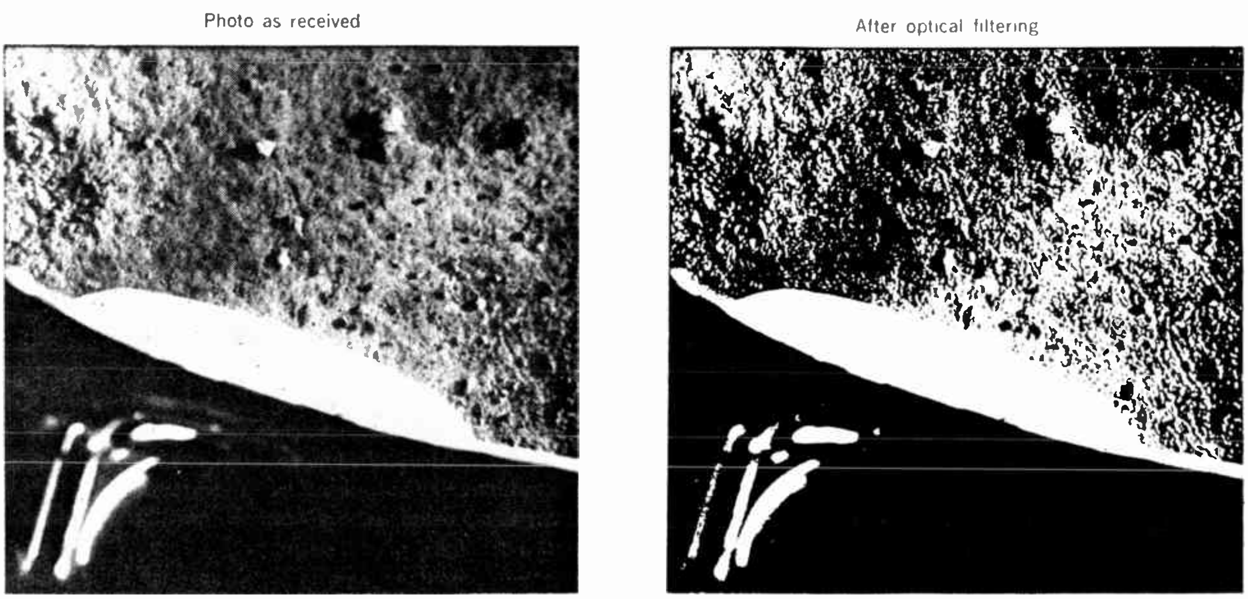
Geological studies

In general, the applications of optical analysis and filtering to certain kinds of geological information[9] fall into two categories: (1) statistical studies of data; (2) filtering of pictorial data such as aerial photographs and photomicrographs so as to extract information that is poorly defined in the original presentation.

A problem frequently encountered in geological studies is the statistical analysis of two-dimensional lineations. Examples include the distribution of directions of lines, such as the traces of rock fractures on aerial photographs or grain boundaries in photomicrographs. Contours of various types as well as drainage patterns may also be analyzed in this way.

Two-dimensional transforms of lineation patterns are particularly suitable for statistical presentation of directional distribution. Preferred orientations are generally obvious to the eye on the transform patterns even when they are not obvious on the original picture. Sometimes the problem is to determine from the statistical distribution of the directions of fractures on aerial photographs whether or not there are preferred orientations. The introductory figures show, for instance, a series of fracture segments traced from an aerial photograph, in which preferred orientations are not distinguishable, whereas the transform pattern shows distinctly that there are three preferred orientations of the fractures, one being more prominent than the other two. The conventional approach to such analysis requires measurement and tabulation of each line segment on the original picture, a for-

FIGURE 9. Improvement in resolution of a photograph of the moon made by Surveyor VI using high-pass spatial filtering.



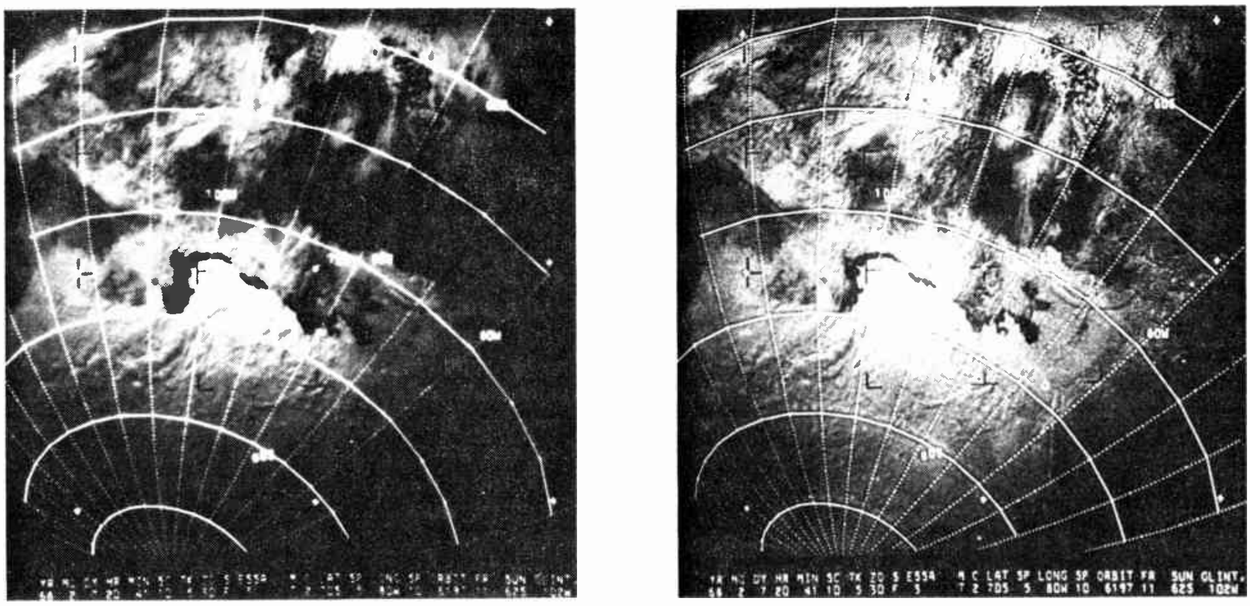


Photo as received — After optical filtering

FIGURE 10. Improvement in resolution of picture from weather satellite over the Antarctic coast using optical high-pass filters.

midable manual task even when the actual calculation is done by an electronic computer.

The analysis of grain-size distributions is also greatly facilitated by the use of optical transforms. The increasing diameter of the transform pattern as the grain dimensions become smaller illustrates the correspondence. Densitometer sweeps across the transforms may be used if it is desirable to determine the grain-size distribution in a more quantitative way.

Optical filtering can be particularly useful in studying geology from aerial photographs where dominant elements obscure weakly developed features of interest. Often prominent stream patterns and lines made by trees or other vegetation trending in one direction conceal marginal indications of fault outcrops trending in other directions. Directional filtering of all lines interfering with the weak fault traces can bring them out so that they become observable.

Another use for optical filtering is to improve resolution of two types of spacecraft pictures. For example, Fig. 9 is a picture made on the moon by Surveyor VI. Using a high-pass optical filter, one is able to enhance the resolution of the picture and observe detailed features of the rocks that were barely visible in the original. The left-hand side of Fig. 10 is a picture received from a weather satellite crossing the coast of the Antarctic continent. Optical filtering was carried out to obtain better definition of the sea ice, clouds, and shoreline; the results are illustrated on the right-hand side.

Conclusion

This brief review suggests the kinds of applications of optical data processing that have been made thus far in the earth sciences. More and more data on the earth and its resources are being obtained by remote sensing; for instance, when the EROS satellite goes into operation next year there should be a vast increase in the amount of information available to those evaluating the earth's resources on a large scale. Optical techniques should have highly promising applications in the reduction and assimilation of these vast quantities of data, which will be largely in pictorial form.

In the future, there should be substantial advances in the capability of optical systems for handling such information. Holographic techniques of matched filtering by pattern recognition should soon be developed to the point where they can be applied effectively along with the more elementary approaches. Optical methods have unique advantages over other techniques for many processing problems. There is little doubt that these methods will see greatly increased use in handling the growing mass of data that is being acquired on the earth and its environment.

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Planning for power—a look at tomorrow's station sizes

With favorable locations for power plants becoming increasingly scarce, future planning must take into consideration the installation of as much capacity as possible at each site, with due regard, of course, for the environmental effects of such superplants

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Favorable sites for utility power stations are becoming more difficult to obtain due to the demands of other industries and urban developments. A utility must plan for generating facilities long in advance of the time they are needed to meet system load growth. A major problem will be to find sufficient sites for the required generating facilities to meet the system demands. Successful planning must consider the types and sizes of generating equipment to come. The author looks into the future to forecast the unit and plant sizes for which plans must be made in the next 20 years.

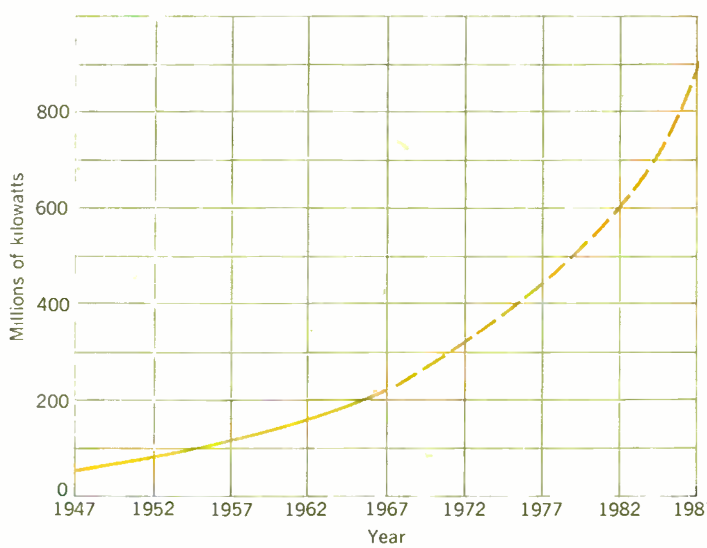
The next two decades undoubtedly will witness major technological changes in the art of generating equipment. Work is now under way on the direct conversion of heat energy to electric energy by means of magnetohydrodynamics, thermionics, and the fuel cell; in the nuclear area, molten-salt and fast breeder reactors are being developed. Multipurpose plants for the production of electricity, drinking water, and minerals, all from seawater, may become a major part of the electric utility business. Although it is probable that within the next 20 years a full-scale plant using one or more of the foregoing concepts will be built, it is not expected that the largest units or largest stations constructed in that period will utilize any of these methods of generation. Except for size, most will be similar to those of today.

One of the most significant developments in the utility industry in the past 20 years has been the increase in generating capacity and in the size of individual units and generating plants. It is expected that this trend will continue and that the largest unit installed in 1987 will be 3000 MW, with the average size approximately 1500 MW; actual sizes will probably be dictated by economics. Site problems will influence plant costs but will not be insurmountable from a technological viewpoint. A reasonable estimate of the maximum station size is 12 000 MW, with an average size of 4000 MW.

From Fig. 1 we see that U.S. peak electrical loads have increased 3.7 times between 1947 and the present and it is estimated that they will increase four times in the next 20 years. In the past an increase in demand has been accompanied by an increase in unit size. Figure 2 illustrates the growth in size of steam units installed since 1947. The average unit size installed has increased more than 700 percent, from 38 MW in 1947 to 280 MW in 1967. The largest unit size has increased from 100 MW in 1947 to 1000 MW today, an increase of 1000 percent. If this same pattern were to continue, the average unit size to be installed in 1987 might be about 2000 MW and the largest about 10 000 MW, but this is not expected to be the case.

The size of steam stations has not increased as dramatically as has individual unit size. The average station size was 34 MW in 1947 and 200 MW in 1967, an increase

FIGURE 1. U. S. electric utility peak loads, 1947–1987.



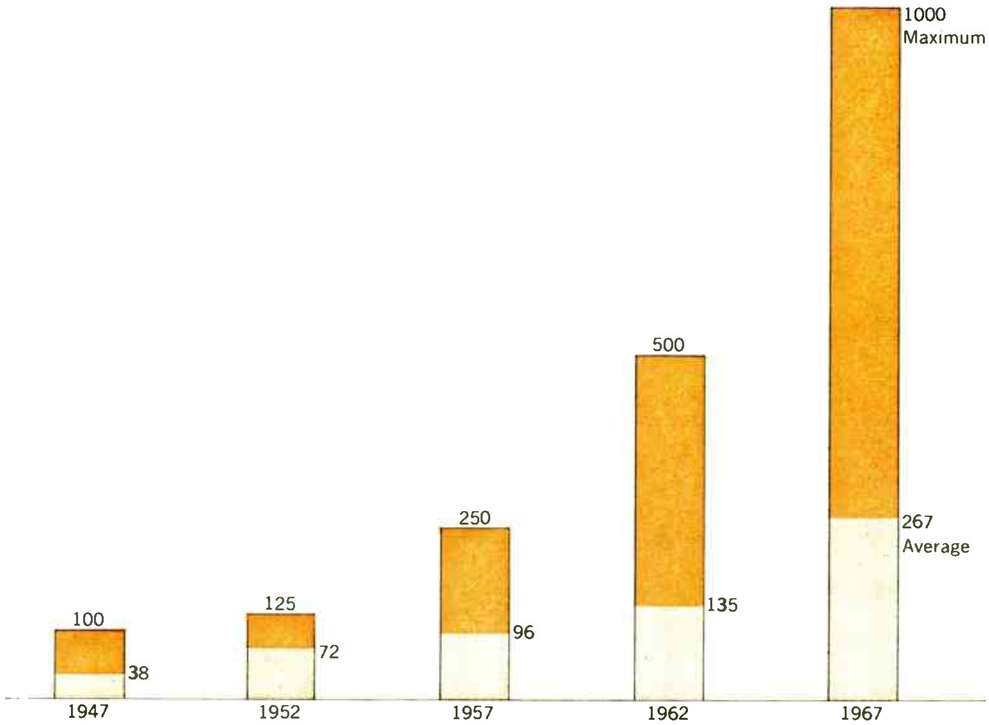


FIGURE 2. Average and maximum steam unit size, 1947–1967, in megawatts.

of 580 percent, whereas the largest station had a capacity of 880 MW in 1947 and 1950 MW in 1967, an increase of 230 percent. Projection of this trend would result in an average station size of 1150 MW, with the largest station at 4500 MW, in 1987. It is expected that the rate of increase in station size will accelerate in the next 20 years. However, rather than simply projecting this trend, it is of interest to investigate the various factors that influence unit and station sizes to determine a rational approach to a prediction of these sizes for the future. These factors include: (1) availability of cooling water; (2) availability of fuel; (3) environmental limitations; (4) electric system limitations; (5) limitations of design, manufacture, and shipment of major plant components; and (6) land requirements.

Availability of cooling water

The most difficult problem to be solved in the development of large plants is to obtain an economic source for condensing the exhaust steam from the condensers. The most economic arrangement is normally a once-through system utilizing water from a river, lake, or ocean. The dissipation of heat from a power plant to a body of water is becoming a major problem. Because of restrictions on temperature rise in rivers, reservoirs, and estuaries, there is a tendency toward the adoption of cooling towers to assist the once-through system in limiting the heat dissipated to the receiving body or to replace the use of natural water supply.

Circulating water requirements for a once-through system are approximately 28 liters (one cubic foot) per second per megawatt of capacity for a fossil-fired unit and 45 liters per second per megawatt for a nuclear plant of the light-water type. A 12 000-MW plant would require 340 000 to 560 000 liters per second to be delivered to the condensers. Only a few major U.S. rivers have a minimum flow in excess of these quantities. The circulating water is returned to the body from which it was obtained at an increase in temperature, which results in an evaporative cooling loss of about one percent of the water circulated. Plants situated on oceans, river estuaries, or some of the larger lakes could obtain this quantity of water from a once-through system with provisions for separation of intake and discharge.

Some parts of the United States have sufficient areas of sparsely settled land and the proper terrain to develop artificial cooling reservoirs, which would depend on runoff from the drainage area or pumping from nearby rivers to supply the required makeup. Such sites require large areas, approximately 1.0 to 1.5 acres (4000 to 6000 square meters) per megawatt for a fossil plant. Thus, a 12 000-MW plant would need a lake of 12 000–18 000 acres (49–73 km^2) for a fossil plant and 19 000–29 000 acres (78–117 km^2) for a nuclear plant.

Cooling towers may be used in areas where there is insufficient water for a once-through cooling system and where the construction of a cooling reservoir is not possible. They will be used to a larger extent in the future as the rather limited number of adequate river- and shorefront sites are employed for utility power plants and industrial uses. Such towers add to the cost of the plant but are a practical alternative if sufficient water for a once-through system is unavailable.

Cooling towers may be of the wet or dry type. The more widely used wet type depends on the evaporation of a small percentage of the circulating water to cool the remainder of the water. The dry type depends on a transfer of heat from the circulating water to the atmosphere by convection and conduction in heat exchangers.

In a wet cooling tower system, discharge water from the condenser is sprayed into the tower and flows over baffles to the bottom of the tower. Air is passed over the water, evaporating a portion of the water and cooling the remainder. The cooled water is then pumped to the condenser. The flow of air through the tower may be created by fans or by the stack effect of a high tower. Approximately 3 to 3½ percent of the water flow to the tower is lost by evaporation, blowdown, and drift.

A wet cooling tower system cannot operate without makeup and thus a source of water must be available. A makeup reservoir may be required if the surrounding streams do not have a sufficient flow throughout the year to provide makeup requirements.

Wet cooling towers require a substantial amount of land, but natural draft towers require less space than mechanical draft towers. Present designs of natural draft cooling towers permit a single tower to serve a 1300-MW fossil-fired unit or an approximately 800-MW nuclear unit although towers of such size have not been built to date. The towers can be spaced at a center-to-center distance of three radii. With improvements in cooling tower design, it is predicted that in the future a single natural draft tower could serve a 2000-MW fossil unit or a 1250-MW nuclear unit.

A mechanical draft wet tower does not appear to be economic for large units except possibly in hot, low-humidity areas where the efficiency of a natural draft tower is reduced.

The dry cooling tower has been introduced to serve arid areas where sufficient water to supply a wet cooling tower is unavailable or prohibitively expensive. Two types of dry cooling towers have been proposed—in one, air-cooled heat exchangers are used to cool the condenser circulating water; the other uses a jet condenser and air-cooled heat exchangers. With either cycle arrangement, airflow through the exchangers may be created mechanically or by the stack effect of a high tower. Air-cooled heat exchangers for cooling liquids are used extensively in process industries but have found little application in utility power plants. Cooling of circulating water in exchangers is feasible but requires an enormous amount of cooling surface for the unit sizes considered for the future.

The Heller cycle utilizes a jet condenser and air-cooled heat exchangers. Cooled condensate is sprayed into the jet condenser to condense the exhaust steam. A portion of the condensate is delivered to the cycle and the remainder is pumped through air-cooled heat exchangers. Heat is transferred to the atmosphere by convection and conduction in the heat exchangers. The cooled condensate is returned to the jet condenser for reuse in condensing the exhaust steam.

One of the major problems in siting the power plants of the future will be in finding an adequate supply of cooling water, and so river- and oceanfront sites will be at a premium. Artificial reservoirs will be available in some areas. Wet cooling towers will be in greater use to serve the cooling requirements or to supplement a natural water supply and dry cooling towers also will be utilized to an increasing extent.

The cooling water problem will be difficult and costly to solve and will be an economic factor in limiting plant sizes in many areas. However, the use of cooling towers, particularly to supplement natural water supplies, will permit the installation of almost unlimited capacity at a site of adequate size.

The use of a wet cooling tower may increase the plant investment by about 6 percent and the overall annual production cost by about 5 percent over those for a once-through system; a dry cooling tower may increase the plant investment by about 14 percent and the annual production cost by about 10 percent.

Availability of fuel

Until a few years ago, fossil fuels and falling water generated all the energy utilized in central station power plants. Now, nuclear energy is achieving a dominant position.

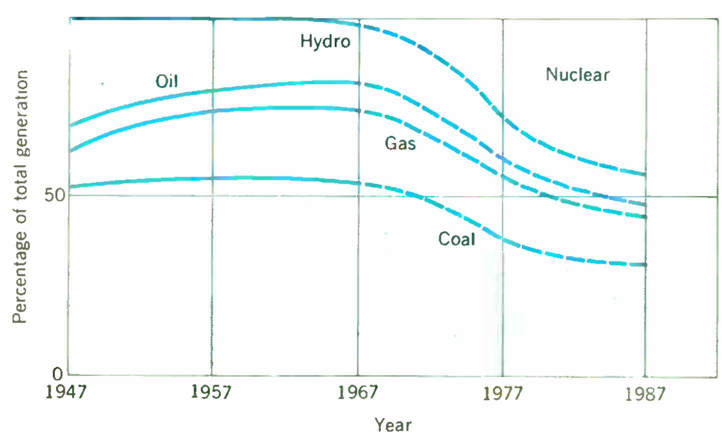
Coal, which has been the main source of fuel for electric generation, as the result of tremendous advances in mining and transportation has remained competitive with other energy sources. However, it is losing ground to nuclear energy as a fuel source for the larger plants, and, as indicated in Fig. 3, will be superseded by the latter as the dominant source within the next 10 to 15 years.

Natural gas supplies many areas of the U.S. today but is expected to become a less important fuel for electric generation. It is becoming increasingly difficult to place long-term contracts for natural gas to serve as boiler fuel, a trend that will continue. A national fuel policy may prohibit or severely restrict use of natural gas for new power plant installation.

Fuel oil has never achieved a dominant position as an energy source for power plants in the United States but has found its maximum use in the coastal areas where transportation poses less of a problem. Changing demands for petroleum products and development of new refinery processes has limited the amount of Bunker C fuel oil available at favorable prices.

The increasing emphasis on the prevention of air pollution will add to the cost of power from coal- or oil-fired plants by necessitating the use of low-sulfur fuel, the desulfurization of the fuel at the point of origin, or the use of equipment for removing sulfur products from the flue gases. Air pollution from large coal- or oil-burning plants has been minimized in the past by the use of tall stacks but this will not be practical for the larger plants of the future. Among the processes

FIGURE 3. Raw energy for electric generation in the United States, 1947–1987.



now under development for the removal of sulfur products from flue gases are methods by which the sulfur would be recaptured for sale as a by-product, thus reducing the economic penalty to be faced by the coal and oil industries. However, in all probability, pollution control will make the competitive position of coal and oil more difficult.

Economic sites for the development of hydro power are scarce and hence its importance will diminish in the future. Nuclear energy will make rapid inroads in predominantly hydro systems as in the Pacific Northwest.

It is expected that future system development will consider nuclear energy for base-load generation. Pumped or storage hydro, gas turbines, or peaking fossil units, together with existing old units, will be used for short-term peaking. The intermediate load will be handled by new fossil-fired units and existing older but still efficient units. The intermediate load units must be capable of daily cycling. This type of system development would dictate the use of nuclear fuel for large power plants, eliminating the problem of fuel delivery and storage.

Prior to the advent of breeder reactors, the availability of uranium to fuel nuclear plants has been a source of concern. However, the history of extraction industries has been that as demand increases, exploration increases, mining technology improves, and more ore is discovered and reclaimed. The development of breeder reactors will be accelerated if this does not prove to be true for the uranium industry.

We then may conclude that availability, shipment, and storage of fuel will not be a serious problem for our large power plants.

Environmental limitations

The air we breathe, the water we use for recreation, the effect of industry on the surrounding area and its vegetation are important to all of us. We are becoming increasingly aware of the influence of an industrial development on its environs, and our large power plants must not contribute unduly to the desecration of our natural resources.

Governmental regulations now in force, or being proposed, will limit the amount of heat that can be discharged to a natural water source and the amount of atmospheric pollution to be permitted at ground level. A once-through cooling system discharges heat to the water source and may affect the ecology of the area. Shellfish may be driven away or their growth retarded due to heated discharge from an oceanfront site. The spawning cycles of fish may be changed as a result of the increased temperature from a riverfront site.

In all probability there will be few sites on which the installation of a large power plant will be permitted without some means of minimizing the effect of heated discharge on the water source. Subaqueous pipe to deep water and diffusion of the discharge to permit complete mixing may accomplish this on an oceanfront site. River sites may require the supplementary use of cooling towers to permit installation of large capacities on the banks of major rivers. The discharge of tremendous quantities of high-humidity air from wet cooling towers may create a fogging problem at ground level under certain atmospheric conditions but the use of high natural draft towers will minimize the problem.

The release of large quantities of heat from a single plant, even through a dry cooling tower, may affect the area surrounding a plant. This condition has not been encountered to date but it may become a cause of future concern. It is difficult at this time to assess the amount of heat that can be released hundreds of feet above grade without an adverse effect.

Although air pollution is a serious problem with oil- and coal-fired plants, the liquid and gaseous radioactive material emitted by nuclear plants is small in amount and can be made insignificant by proper treatment. The radioactive gaseous effluents can be rendered harmless with proper holdup time before release and the liquid wastes can be collected and treated in ion exchangers or by evaporation.

Solid wastes are disposed of by baling and underground storage. Disposal at sea has been abandoned, at least in the United States, but may be utilized when more secure containers are developed. The sea would provide an almost limitless storage facility for the disposal of solid wastes.

The location of nuclear power plants is governed by the regulations of the Atomic Energy Commission. Currently, the siting of nuclear plants is affected by three areas of major concern:

1. The influence of seismic conditions on the approval of a site. It is expected that guidance will be provided by the AEC on these problems, which may rule out some areas but will not seriously restrict approval at other sites.

2. The rapid increase in the capacity of proposed stations without any operating experience. The AEC and the Advisory Committee on Reactor Safeguards have expressed concern at this situation but this has not prevented the issuance of construction permits for large units and it can be expected that, as experience is accumulated, progressively larger units will be approved. The exclusion distance from the reactor to the property line is generally calculated on the basis of conservative assumptions and is now a function of unit size, not station size. As more experience is obtained with engineered safeguards, a relaxation in the required distances can be expected, and so it is not expected that the projected increase in unit size would create a siting problem.

3. The reluctance on the part of the AEC to approve metropolitan sites. Containment designs and engineered safeguards have been proposed for metropolitan sites, which, in principle, meet the letter of the AEC criteria. However, the problem remains that if the safeguards are not completely reliable there is no secondary defense in distance or time to take protective action. Experience with large stations now under construction will help prove the reliability of the containment and the engineered safeguards. It may be many years before a metropolitan site will be approved; our best estimate is that such approval will be obtained by about 1980.

Electric system limitations

Electric systems are becoming larger not only through growth but also through consolidation. In the past 20 years the number of investor-owned utilities has been reduced from 320 to less than 210. This trend will undoubtedly continue.

In addition to system mergers, the trend to power pooling will also accelerate. Some of the loosely knit power pools will become stronger with a central organization responsible for planning, construction, and operation of bulk power facilities. These trends will increase the need for large generating units and will require careful consideration of transmission requirements, reserve requirements, and availability of larger units.

Transmission grids will be extended throughout the U.S. so that extensive transmission probably will not be required to tie the large plants into the network. Increased emphasis will be placed on the use of underground cables, particularly near urban areas.

In order to obtain the same degree of reliability, it is probable that the larger unit sizes will require a greater reserve capacity. Experience to date indicates that availability decreases as unit size increases. However, another factor also influences these statistics—the maturity trends. Units become more reliable as they mature. The larger units, with fewer years of service behind them, have not eliminated the initial break-in problems as the smaller units have.

Larger units, with more tubes in the steam generators, casings, bearing, pumps, valves, piping, welds, relays, controls, and all the many items that constitute a major power plant, are more subject to failure than are smaller units. It will take ingenuity and care on the part of the designer, the manufacturer, and the constructor to minimize the effect of size on reliability. Increased reliability can be assured by the utilization of computers in engineering for more precise design of materials, by improved metallurgy, by using solid-state electric devices, by improving quality control in shop and field with the use of nondestructive testing equipment, and by utilizing computers and increased plant automation to achieve better operation. It may be necessary to incorporate larger design margins in an attempt to obtain the same reliability in equipment with more and larger components. The greater use of spare equipment will be resisted as this tends to defeat the economy of size. More sophisticated system controls will be required to prevent loss of stability on failure of a large unit. However, these approaches to design are now under way and should create no problems in the future.

The concentration of generating resources would increase the risks of a loss of sizable amounts of capacity due to fire, earthquake, hurricane, war, and other causes. Possibly insurance carriers would place a limitation on the amount of insurance they would offer at any one site or require higher premiums for full coverage.

The electric systems will be able to accept unit and plant sizes as they become available after a careful study of the economics. More generating and transmission capacity, spinning reserve, and other requirements for reliability can be installed, limited only by the overall costs to the system.

Size limitations of major plant components

As units increase in size, some components may approach a size where multiple units may be less costly than a single unit of the same capacity. This approach can be justified for auxiliary equipment but when multiple turbine generators, steam generating units, or reactors are required, then a unit size limitation is reached.

The limiting factor on unit size appears to be the turbine generator. Historically, the steam-generator manufacturers have been able to produce larger units to accommodate the development of turbine generators.

I. Increase in the size of nuclear units

Year of Initial Operation	Largest Nuclear Unit Installed in Year, MW	Average Nuclear Unit Installed in Year, MW
1960	200	200
1961	175	175
1962	265	120
1963	70	40
1964	—	—
1965	—	—
1966	790	270
1967	40	40
1968	640	480
1969	1030	590
1970	1150	730
1971	1150	770
1972	1100	850
1973	1100	860

In the future it will be necessary for the nuclear-steam-supply manufacturers to maintain this pace. There is ample reason to believe that nuclear units will be available in the future that are much larger than units available today. The increase in the size of nuclear units has been dramatic, as indicated in Table I.

The plateau around 1100 MW is believed to be temporary and larger units can be expected in the future. The General Electric Company performed a feasibility study of boiling-water-reactor-nuclear steam supply systems for Oak Ridge National laboratory. Their report indicated that BWR nuclear steam supply systems with capacities up to 10 000 MW (t), based on current technology, could be ordered by 1975. The GE study examined such critical areas as pressure vessel technology, steam separator and dryer capability, coolant pumps, core physics, reactor kinetics, and refueling time. Both steel and reinforced-concrete reactor vessels appear to be feasible for power levels at least as high as 10 000 MW (t) and none of the other areas show any serious obstacles to increase in size.

A similar report by Gulf Atomic indicates that 10 000-MW (t) high-temperature gas-cooled reactors are also feasible. In this case a somewhat longer development schedule is suggested but an operating date of 1980 is considered feasible.

There is every reason to believe that sodium-cooled reactors are inherently capable of extrapolation to sizes even larger than feasible with water-cooled reactors. These reactors would operate at most pressures so that the reactor vessel diameter can be increased readily without serious problems in vessel wall thickness. Also, the power density is higher than for water reactors.

Turbine-generator manufacturers are considering larger units for the future. An estimate of unit size that may be available is shown in Fig. 4. It is probable that 1500-MW units will be available for operation in 1976, 1950 MW in 1977, 2000 MW in 1979, 2500 MW in 1983, and 3000 MW in 1985.

Tandem compound units for fossil-fired plants will probably be limited to about 1650 MW and for nuclear application to about 2000 MW. Increased capability for both fossil and nuclear units can be obtained by the use of cross-compound units up to the estimated limit of about 3000 MW. This increase in size will be obtained

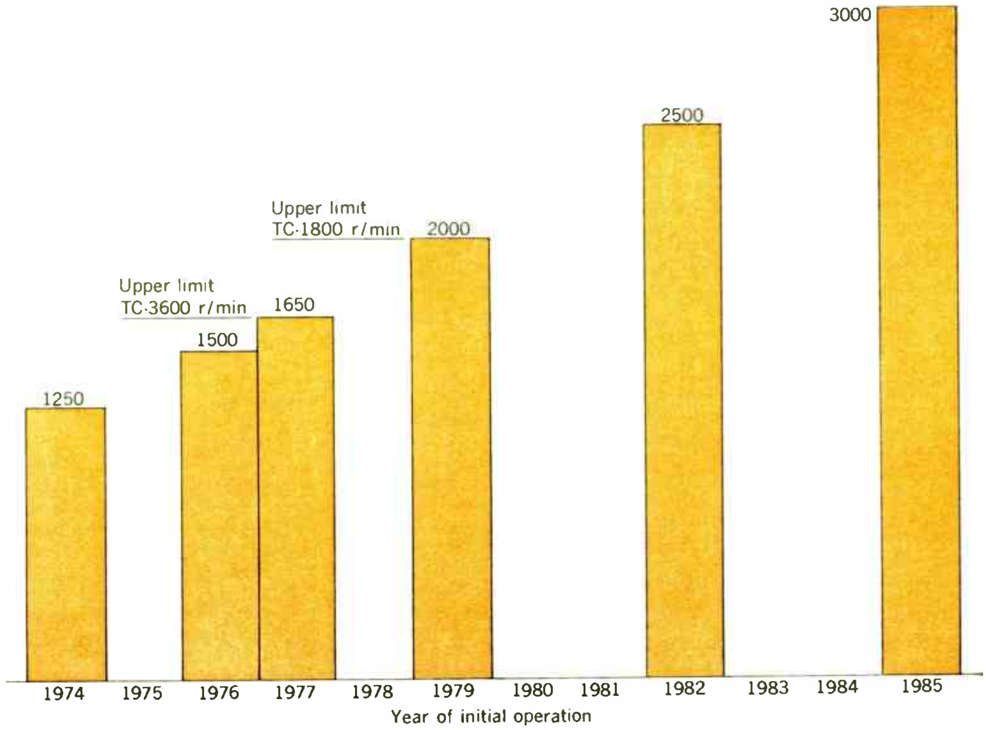


FIGURE 4. Maximum turbine-generator unit size, megawatts.

through improved metallurgy, longer blade design, and new manufacturing techniques. More field fabrication will be required for these units as a completely shop-fabricated unit will be too large to ship. Low-pressure blades will be field installed, turbine casings will be sectioned for field assembly, and generator stators will be shipped in sections for assembly in the field.

At some unit size the trend of decreasing unit costs with large sizes may be reversed due to the increased costs of the field assembly required. It is a matter of conjecture as to where this breakpoint would occur. In the past, plots of unit size with cost per kilowatt have reached a bottom somewhat beyond the size of units being considered at the time the plot was made; at a later date, a similar plot would show the bottom to occur somewhat beyond the then-current largest size unit. There is no reason to anticipate that the economy of size trend will be reversed in the next 20 years.

Land requirements

Large sites will be required for the plants of the 1980s. Land requirements will be dictated for the most part by the AEC requirements for exclusion. Assuming an exclusion distance of 760 meters, a 12 000-MW plant would require property about 2300 by 1800 meters or about 4.1 km^2 (1000 acres).

Urban siting probably would not require this amount of property. However, a metropolitan station would undoubtedly be more costly in order to incorporate the additional safeguards considered necessary in lieu of exclusion distance.

Future nuclear stations may be located underground or under the sea, which would further reduce property requirements. However, this development probably will not be a factor for the next 20 years.

Conclusions

An examination of the various factors involved indicates that station size is a matter of economics. The limiting factors are the cost of building the station, transmitting the power, and providing for system reliability from one large facility as compared with installing the same amount of power in several locations.

It is realized that the utmost consideration must be given to the environmental effect of this superplant. No data are available today but it is possible that the release of large quantities of heat from a single plant, even through a dry cooling tower, may affect the area surrounding the plant.

Assuming that this problem will not exist, our large station in the 1980s will include 3000-MW units; the number will depend on the system size. The trend toward consolidation of electric systems, pooling of generation, and participation in joint generating stations will result in economic justification for increasingly larger stations. The number of attractive sites for large plants is limited and so consideration will be given to installing as much capacity as possible at each site. It is reasonable to expect that four of these units would be located at a favorable site for an aggregate capacity of 12 000 MW.

The average unit and station size will probably be closer to the maximum unit and station size in the future than in the past. Stations will be built to serve large interconnected systems rather than small isolated systems. Many of the small stations now in service will become obsolete and be retired within the next 20 years.

The average unit size installed in the late 1980s will probably be about 1500 MW and the average station size in service at that time about 4000 MW.

Essentially full text of a paper presented at the American Power Conference, Chicago, Ill., April 23–25, 1968.

FIGURE 1. Old woodcut showing Dr. Werner von Siemens' electric tramway locomotive as it hauled visitors to the Berlin Exposition in 1879.

Railroad electrification: past, present, and future

Development of the great European systems

At the turn of the 20th century, the hydro power potential of Italy, Switzerland, Austria-Hungary, France, and Germany was explored for proposed railway electrification schemes. Today, this source of generation—augmented by fossil-fuel and nuclear power plants provides the motive power for railroads in Europe and Great Britain

Gordon D. Friedlander *Staff Writer*

For all practical purposes, the first successful application of electric railway traction dates back to 1879, when Dr. Werner von Siemens' grotesque little locomotive (Fig. 1) hauled passengers around the grounds of an exposition site in Berlin. In 1881, the first public railway service was inaugurated in that city. By 1883, the first part of Magnus Volk's electric railway at Brighton, England, was completed; and, by 1890, the City & South London Railway began service as England's first underground system. Because of the generally smaller geographic areas of most European countries, the availability of hydro power (in alpine regions), and the lag in modern highway programs, both Europe and Great Britain have been more dependent on their railway systems—even to the present time—than the United States. Thus the trend has been toward complete electrification of rail lines in Italy, Germany, Switzerland, and Austria. In Great Britain, however, the emphasis is equally upon diesel–electric traction; and this form of tractive power has found some favor on the Continent.

Electric railways depend entirely upon the distribution of electricity by means of convenient electrical centers. The experiments made in 1879 in Berlin, and last year in Paris, show that the quest is practically solved; in fact, an electric railway has lately been established in Berlin. . .

—Dr. Werner von Siemens, 1881

Following Siemens' successful pioneer application of electric power to a traction vehicle in 1879, considerable effort was subsequently undertaken by Siemens' engineers in France and Germany to develop improved versions of the prototype. During this research period, the first crude catenary was developed to overcome service interruptions caused by dirt clinging to the surface of the third-rail conductors. It was described by two Siemens Company engineers (Boistel and Sappey) as "two conducting tubes supported at specific distances by posts, and in the intervals by iron wires like the floor of a suspension bridge."

In 1883, Siemens Bros. Limited (the English branch of the German firm) introduced electric traction to the British Isles by equipping a 10-km-long railway between

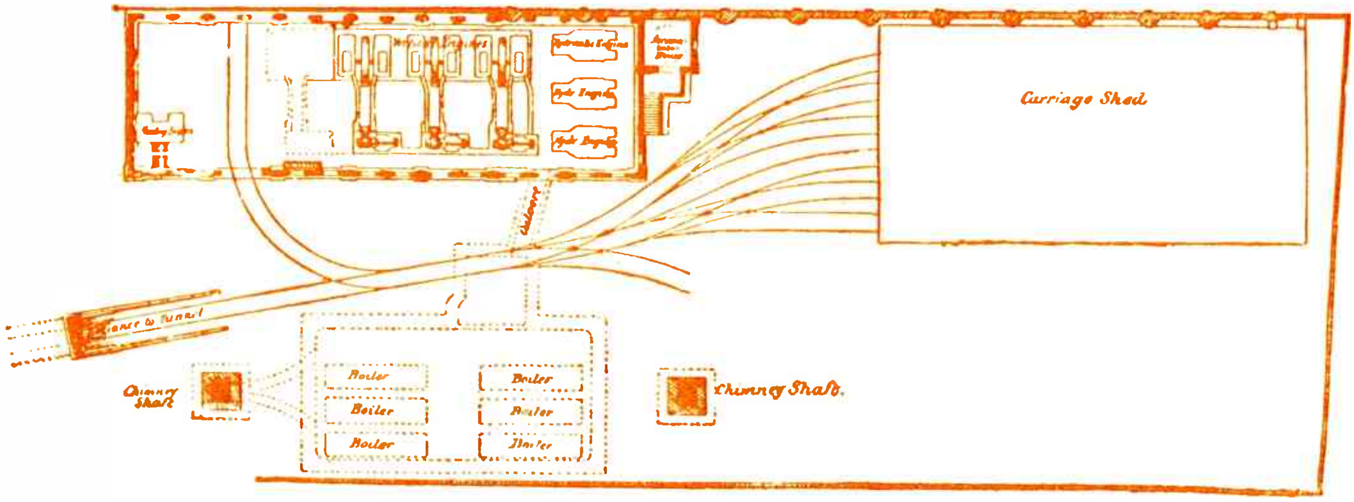


FIGURE 2. Plan view of the Stockwell generating station and carriage shed, built for the City and South London Electric Railway in 1890.

Portrush and Bushmills, in Northern Ireland, with a third-rail conductor system.[1] Power was derived from two water turbines, thereby marking this as the first instance in which hydro power was used in railway electrification. But it was only in the final decade of the 19th century that electricity for transportation began to show its true possibilities.

City and South London Electric Railway

The completion of the City and South London Electric Railway was a landmark in the application of electric locomotion to railway passenger requirements, particularly in densely populated metropolitan areas. The line was formally inaugurated by the Princess of Wales on November 4, 1890, and opened to public use on December 18 of that year.

This line, which was 5.2 km long, extended from the Monument in the City of London to Stockwell, on the south side of the River Thames. It was the world's first underground electric tube railway. The generating station for this pioneering public railway system was at Stockwell (Fig. 2) and it contained three large Edison-Hopkinson-type dynamos, each of which developed 450 amperes at 500 volts. These machines were driven by three vertical-compound reciprocating steam engines. From the generating room, four feeder mains carried the electric energy to distribution switchboards where the current was then conveyed to the feeding points of the third-rail conductor.

The third rail consisted of a specially rolled steel rail carried on glass insulators between, and about 2.5 cm below the level of, the running rails. Each rail length was joined by fish plates and bolts, but electrical continuity was ensured by means of laminated copper strips riveted to the steel conductor. The current return was carried by one of the running rails, which was also connected by copper strips.

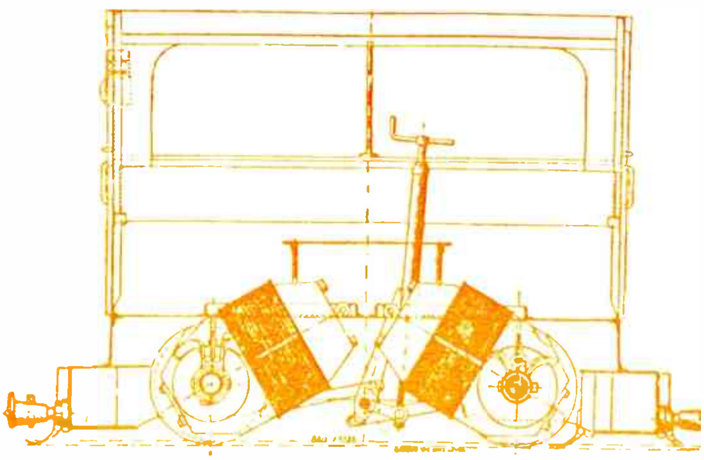
The locomotives (Fig. 3) were—from an electrical and historical viewpoint—the most interesting feature of the system. Each engine was driven by two motors whose armatures were built on the running axles of the wheels so that reduction gears were not required. The massive field magnets were partially supported by the axles and partially suspended from the frame of the locomotive. The magnets were series-wound, and the direction of armature rotation was controlled by a current-reversing switch. When running at 32 km/h, the rotation of the armature was about 250 r/min.

The current was collected from the conductor by means of three cast-iron overrunning contact shoes, from which it was carried to the main resistance switch that controlled both motors. The regulating resistances were in series with the motors and were gradually cut out as the speed increased.

About 20 locomotives were built for the line between 1889 and 1895. Each weighed about 10 tonnes and was capable of exerting a drawbar pull of 1400 kg; maximum operating speed was approximately 40 km/h.

A train consisted of a locomotive and three carriages; each carriage was designed to accommodate 34 passengers. During peak periods 16 or 17 trains per hour were run in each direction. The original equipment remained in service until the line was rebuilt and re-equipped as part of the London Underground Railways system in 1924.

FIGURE 3. Inboard profile of one of the electric locomotives used to haul passenger trains on the City and South London Railway. They were in service from 1890 to 1921.



Electrification begins on the Italian railways

Italy was one of the first countries to use electric traction for mainline service.[2] On February 8, 1899, the Società Mediterranea inaugurated passenger operations on the rail line between Milan and Monza (about 20 km) with battery-powered motorcars. In 1901, a similar line and rolling stock were completed by the Società Adriatica to carry passengers between Bologna and San Felice, a distance of 30 km. Neither system proved to be successful, however; the cars were slow-moving, and the batteries had to be recharged frequently. The service on these lines was abandoned in 1903 and 1904.

First installation of a third-rail line. After a period of extensive testing at the turn of the century, the Società Mediterranea began regular passenger electrified service on a line between Milan and Varese (about 73 route-kilometers of single and double track) in 1901, with seven two-unit "automotrici elettrichi" (motorcars). Electric power for the system was generated at the Tornavento hydro plant, situated about midway between the terminal points. From this power plant, a 13 500-volt transmission line conveyed the electric energy to four intermediate substations along the right of way, where rotary converters transformed the alternating current to 650-volt direct current. Feeder lines from each substation supplied current at this voltage to an overrunning third-rail conductor, a cross section of which is shown in Fig. 4. The conductor was shielded by wooden guard rails mounted on porcelain insulators.

This line proved to be so popular for passenger service that the motorcars could not handle the volume of the increased traffic. Thus electric locomotives of the type shown in Fig. 5 were built to haul both passenger and freight trains. These 34-tonne engines developed 220 kW at a maximum speed of 60 km/h. Two series excitation motors transmitted power to the four drive wheels by means of triple-reduction gears.

The Valtellinesi lines: first to use three-phase current. In 1901, Italy decided to proceed with a major mainline electrification project—the 109-km-long Valtellinesi railway lines in the Lepontine Alps (Lecco–Colico and Sondrio–Chiavenna). An international competition was announced for the design of the proposed power transmission–distribution system and the traction vehicles. The winner was the Austro-Hungarian firm, Società Ganz, whose proposal at that point in time seemed quite "far out" and daring. The scheme was formulated by a Hungarian electrical engineer, Kàlmàn Kandò (see page 90), who proposed the use of an overhead, two-wire 3400-volt three-phase 15-Hz system. It also included the construction of a hydro power station at Morbegno, a 20 000-volt transmission line, and nine substations.[3]

The project, which attracted international interest, was completed in 1902. The first locomotives for the line, rather awkward and primitive-looking eight wheelers (Fig. 6) rated at 440 kW, were capable of hauling a 300-tonne train. These steeple-cab engines were built in two articulated sections, permanently coupled by a pivot joint and bellows connection. Two motors—one with eight poles for high voltage (primary) and the other with six poles for low voltage (secondary)—were mounted on each four-wheel truck (Fig. 7). With the combination of the two motors in parallel, the higher speed of 60 km/h could be obtained, whereas the combination in cascade produced just half the rotational speed to attain 30 km/h.

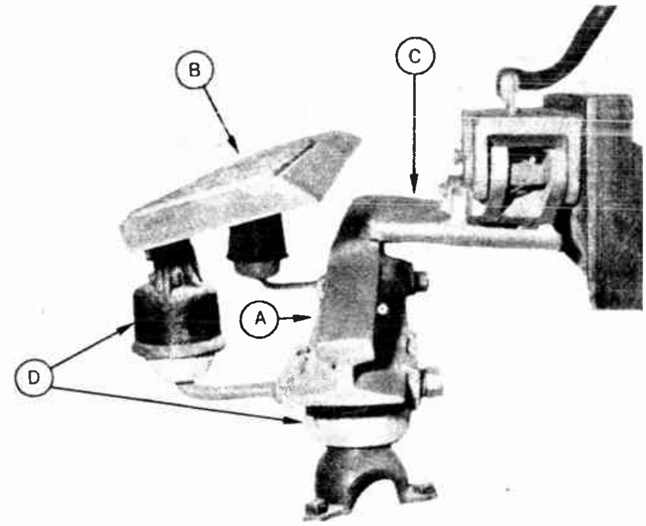


FIGURE 4. Cross section of an early third-rail conductor arrangement as used on the Italian railway system. Symbol A indicates the third rail; B, the wood protective covering; C, overrunning third-rail shoe from locomotive; and D indicates the porcelain insulators.

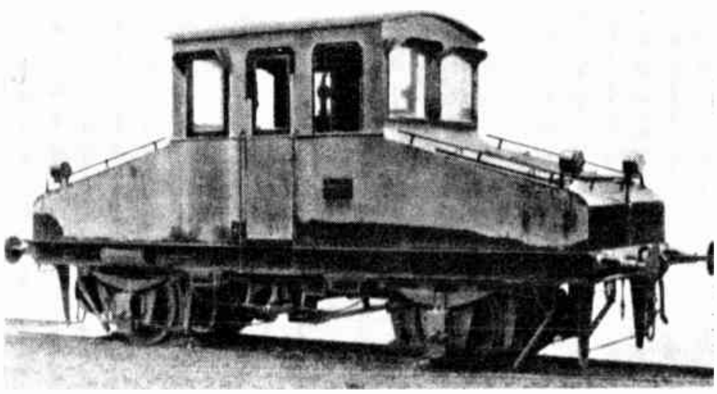
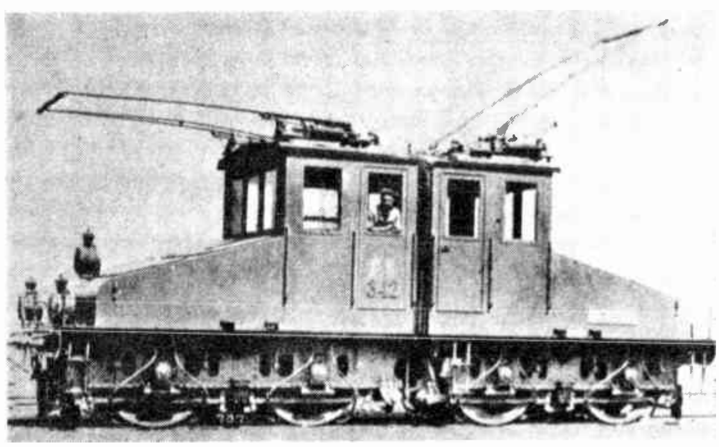


FIGURE 5. Italian railway locomotive, built in 1901, for Milan–Varese passenger and freight service. Note third-rail pickup shoes attached to axle boxes.

FIGURE 6. View of one of the two-section 1902-class Italian eight-wheel locomotives built for the three-phase Valtellinesi overhead electrification.



Until the successful completion of the Valtellinesi lines, it was generally believed that current could not be efficiently transmitted over a trolley at more than 3000 volts because of the difficulties in properly insulating the conductors at support points. Further, at the turn of the century, 45 Hz was standard for European light and power, but this proved to be too high for direct-drive electric traction motors. To use 45 Hz at this stage of the technology would have required complex speed-reduction gears between the motors and the drive axles. Instead, the selection of the 15-Hz frequency made it possible to build rather slow motors and to transmit power (direct drive) to the wheels without gearing. In addition this frequency kept the reactance and impedance of the line at low levels; thus the required number of intermediate substations was reduced and a small cross section could be used for the overhead conductor wires.

There were a number of disadvantages inherent, however, in the use of three-phase conductor systems and motors. First of all, two overhead conductor wires (Fig. 8) were necessary, plus a running rail to complete the third phase. Two conductor wires were not only more expensive than one, but also produced almost insurmountable difficulties at switch points and crossings—particularly at the high voltage required for mainline electrification. Although the three-phase motor was simple and reliable, it could only operate at two speeds in the motor combinations previously indicated. Later motors of this type were equipped with intermediate steps to provide better speed control.

The 'Ferrovie dello Stato'

In 1905, the three principal Italian railway companies were merged and consolidated into what is the present-day Ferrovie dello Stato (Italian State Railroads). This unification had an eventual therapeutic effect in channeling subsequent R & D toward the high degree of railway electrification that exists in modern Italy.

Larger engines for third-rail service. Italy, like the United States, was initially caught up in the third rail–overhead dichotomy in planning. Thus the lines originally equipped either with a third rail or three-phase overhead system remained for many years before conversion to a standardized universal conductor for all mainline service.

From 1900 to 1912, the traffic on the Milan–Varese line (extended to Porto Ceresio in 1902) increased so greatly that in 1912 and 1913, respectively, two new groups of electric locomotives (classes E 220 and E 320) were placed in service. Each of the larger E 320 engines weighed 72 tonnes and had a power rating of 1200 kW from two series excitation-type motors. The E 320s could haul a 300-tonne passenger or freight train at a maximum speed of about 100 km/h. The power transmission from the motors was accomplished by counterweighted eccentric driving rods to two auxiliary axles that were coupled together by means of a direct rod with a central opening into which the bearing of the crank pin could slide. The basic E 320 series was slightly updated in 1921 by the modified E 321 type (650 volts, 16.7 Hz), in which a triangular connecting rod (Fig. 9) replaced the direct rod. This Hungarian-designed drive system, first used on the three-phase locomotives in 1906, was standard on almost all Italian electrics until 1930.

In 1925, the final locomotive (E 620) was built for

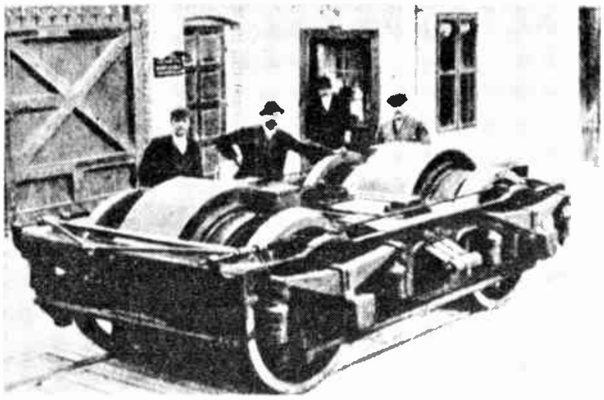
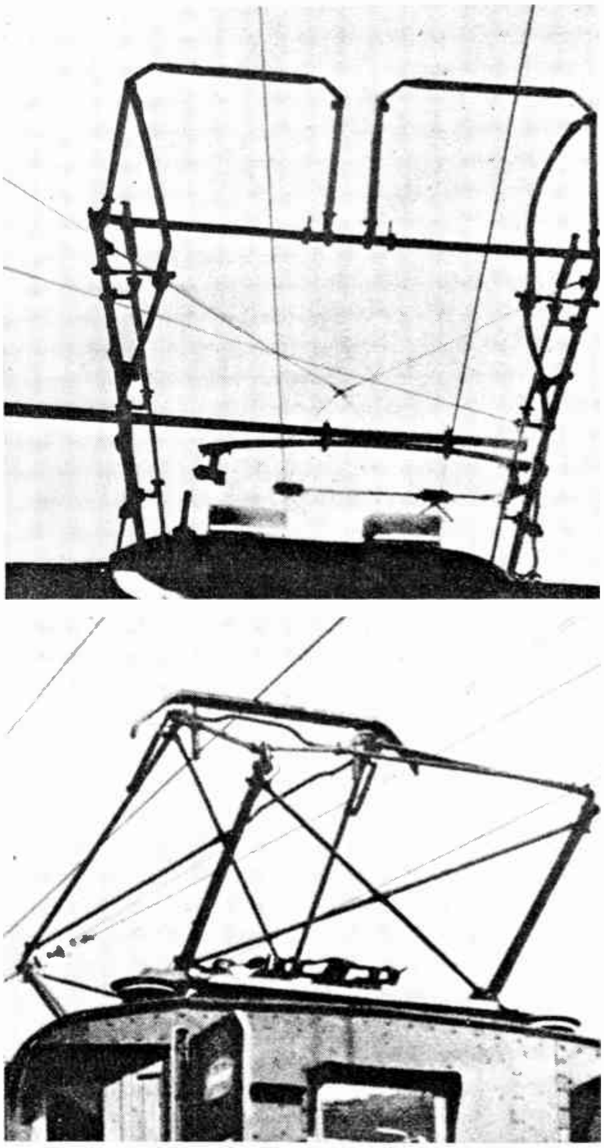


FIGURE 7. One of the power trucks for the type of locomotive shown in Fig. 6. Two motors, one with eight poles for high voltage and the other with six poles for low voltage, were installed in this assembly.

FIGURE 8. Two types of Italian overhead conductors and pantographs: (top) the three-phase two-wire system used until the end of World War II; (bottom) the single-wire conductor and pantograph standard on present-day Italian rail lines (Ferrovie dello Stato).



third-rail service. This steeple-cab engine was divided into two propulsion trucks of three axles each. In appearance it closely resembled some of the switching locomotives used in the United States. It was rated at 1350 kW, with a maximum speed of 85 km/h.

The incorporation of a metadyne unit permitted the post-World War II conversion of this locomotive to 3000-volt dc overhead single-contract wire now standard on the FS. Thus modified, E 620 is still being used for switchyard service.

Extension of three-phase alpine electrification. In 1904, electric locomotives of the general type shown in Fig. 10 (3400 volt, 15 Hz) were placed in transalpine freight and passenger service. Engines such as these hauled the famous Simplon–Orient Express for several years following the inauguration of this Italian–Swiss international route through the Simplon Tunnel (Galleria del Sempione) in 1906. One class of these locomotives, designated as E 38 and rated at 1250 kW, was equipped with two motors—one for high and the other for low voltage—that were operated in cascade and parallel combinations to attain speeds of 37 and 70 km/h respectively. The motors were arranged between the coupled axles, and power transmission was achieved by means of the standard triangular connecting rod and eccentric driving rods. Counterweighted drive wheels ensured uniform application of torque.

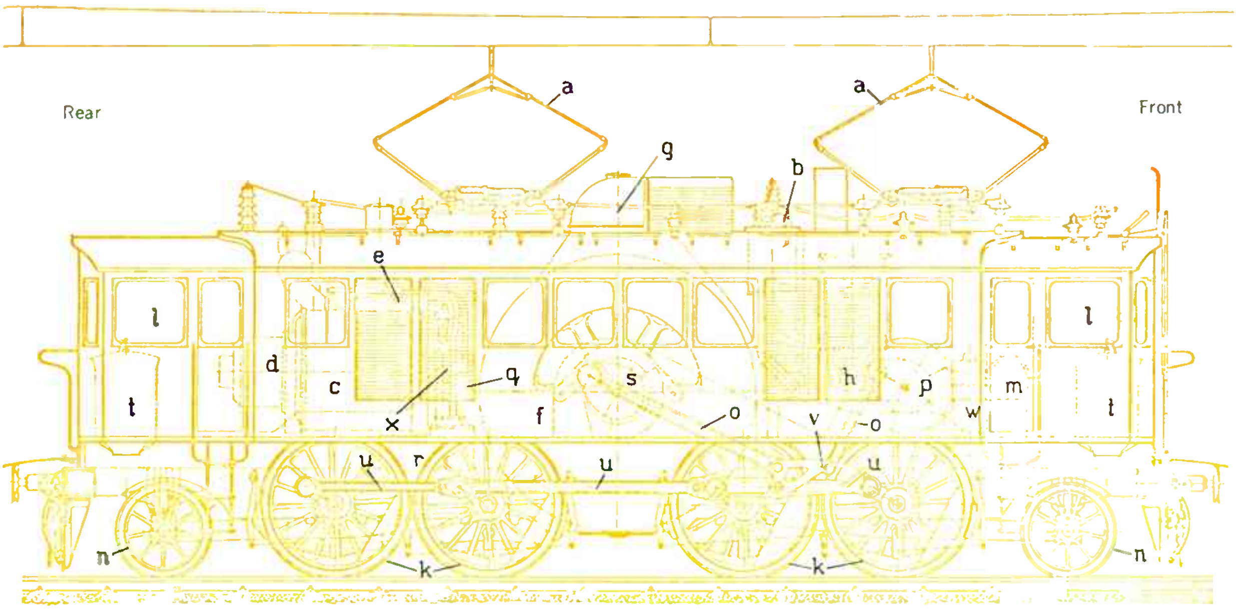
Pneumatically raised rectangular-frame trolleys, equipped with rollers, collected current from the two-wire overhead trolleys. The safety apparatus consisted of two impedance spirals, a three-phase lightning arrester, an automatic oil-immersed circuit breaker, and various fuses for the secondary circuits. Auxiliary services, such as passenger-car lighting, heating, etc., used two three-phase 3000/110-volt transformers.

Three-phase on the 'Giovi lines.' In 1905, the FS decided to electrify two of the rail lines from the port of Genoa—via the Busalla Tunnel and Mignanego—through the Giovi Pass to towns in the northwestern province of Piemonte, most of which is in a mountainous region interlaced with many tunnels and passes. In this area, maximum grades reached 3.5 percent and there were many reverse curves with radii as small as 400 meters. Although construction on this project started early in 1907, it was not until March 1911 that electric service commenced on the Pontedecimo–Busalla section. By the end of that year, service was inaugurated on the stretch between Busalla–Bivio and Rivarolo–Campasso. From 1913 to 1916, three other sections of the heavily trafficked, 300-km-long electrified network were completed from the interior to Genoa.

The principal traction unit of the Giovi lines was the 63-tonne 1500-kW, type E 550 locomotive, which, like its three-phase predecessors, had two speed combinations: 25 km/h and 50 km/h. Each locomotive of this class was equipped with two asynchronous three-phase 3400-volt 15-Hz eight-pole motors, with slip rings and rheostat (for regenerative braking).

An interesting aspect of the early electric locomotive design and construction was its international flavor and composite nature. For example, the mechanical design of the E 550s (and other types) was handled by the research

FIGURE 9. Inboard profile of a Kandò-designed electric locomotive, featuring the "mechanical triangle" drive that was standard on most Italian and Hungarian locomotives for many years.



Legend:
- a Current collector
- b Oil circuit breaker
- c Phase converter
- d Exciter
- e Oil and water-cooling device of the phase converter
- f Traction motor
- g Fan of the traction motor
- h Liquid starter
- k Driving axles
- l Driver's cab
- m Compressors
- n Running axles
- o Driving rods
- p Auxiliary shaft
- q Cooling water circulating pump
- r Cooling water tank
- s Driving crank
- t Master controller
- u Coupling rods
- v Kando articulated frame
- w Pumps of the liquid starter
- x Auxiliary pump for the cooling water.

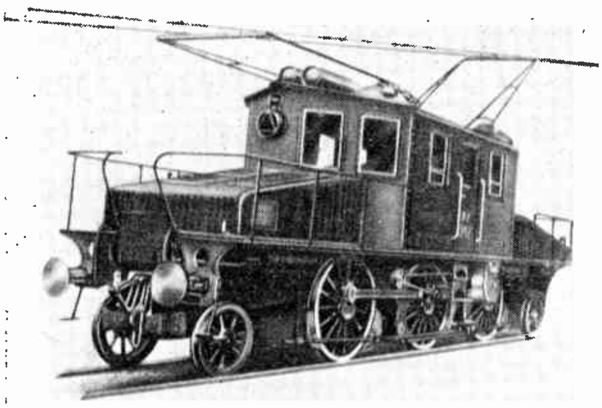


FIGURE 10. One of the three-phase 15-Hz locomotives originally built for Italian railway alpine service in 1904. Locomotives similar to the one shown here hauled the famous Simplon–Orient Express from 1906 to 1914.

bureau of the State Railroad (FS) administration; the electrical design was planned by the Società Italiana Westinghouse, where many technicians of the Ganz company—including Kandò—were employed. The trolley equipment was furnished by the Italian firm of Tecnomasio Brown-Boveri. Actual construction and assembly were in the Breda shops.

Other three-phase projects and later locomotives. Following the initial success of the Giovi lines, three-phase overhead electrification was installed, from 1914 to 1920, on the following routes: Savona–Ceva, Sampierdarena–Savona, and Turin–Modane.

In 1914, European public utility frequency was raised from 45 to 50 Hz; the railway line voltage was increased from 3400 to 3600 volts, and the frequency was raised to 16.7 Hz (one third of the industrial frequency).

The end of the first phase of Italian railway electrification is generally considered to be 1920, when a period of political strife and turbulence caused a three-year hiatus in the electrification program. By 1920, however, a total of 913.4 km of electrified track—767.4 km of three-phase, and 146 km third rail—had been completed.

Locomotive construction for the three-phase service, however, continued apace during the period from 1914 to 1922, with some modified and updated versions of the E 550 prototype. Engines such as the E 551, E 552, E 554, and E 432 types were heavier and more powerful—77 to 94 tonnes, with ratings up to 2200 kW.

Three-phase 3600-volt electrification of additional rail lines in northern and central Italy was completed during the period from 1923 to 1927.

Beginning in 1927, the FS experimented extensively on a specially electrified, 172-km-long three-phase line between Rome and Sulmona, over which 10 000 volts was carried at the standard industrial frequency of 50 Hz. Three groups of Breda-built locomotives (classes E 470, E 472, and E 570) were built for this service. They were heavy and complex engines by FS standards (about 100 tonnes), capable of four speed settings: 37.5, 50, 75, and 100 km/h. These engines were each equipped with two asynchronous, forced-air-cooled 12-pole motors.

The Rome-Sulmona line remained in service until 1943, when it was destroyed by Allied aerial bombardment. And although it gave satisfactory service, the three-phase 50-Hz electrification scheme was never extended because there were too many doubts as to whether it was an optimum system.

Advent of 3000-volt dc: the big debate

From 1920 to 1927, an internal battle had raged within the FS administration between the factions favoring the completion of a three-phase network throughout Italy and those favoring the conversion to single-wire direct current to conform with the other European electrified systems. The former group stressed the simplicity of power transmission with three-phase: few substations containing only the necessary transformers. Also, the low weight per kilowatt ratio of the locomotives was a salient economic advantage. For example, a three-phase locomotive, rated at 2000 kW, weighed only 75 tonnes. And finally, dynamic braking for checking the rate of descent on Alpine grades, and the successful—but limited—use of standard 50-Hz current, were cogent arguments.

But on the debit side of three-phase operation were

1. The complexity and difficulty of installing the two-wire lines at switches, crossings, and in terminal interlocking systems.
2. The limited speed settings possible with the traction motor combinations.

On the other hand, the proponents of single-wire direct current emphasized the following advantages of their scheme:

1. The relative simplicity of erecting the overhead lines.
2. The smooth acceleration of dc traction motors and the variable speed settings possible between zero and a locomotive's maximum velocity.

But the disadvantages included the high cost of con-

FIGURE 11. Breda-built Italian State Railways locomotive of the E 428 class. This group of 135-tonne engines and class E 326, built between 1930 and 1934, were equipped for service with the now standard 3000-volt dc overhead trolley. Both classes are still in service.

structing numerous wayside substations containing complex and expensive apparatus for the conversion of three-phase current to direct current.

In 1928, after considerable debate and discussion within the FS administration, the first 3000-volt dc overhead line was constructed between Benevento and Foggia, a distance of 90 km. By a fortuitous coincidence, the mercury-arc rectifier—offering a major advantage in its application to dc traction systems—became available in that same year, and this equipment was installed in the substations of the Benevento–Foggia line.

For this initial service, locomotives of the E 626 class were specially built. Rated at 2100 kW, each of these 93-tonne engines was equipped with six motors, capable of operating in series, in parallel, or in series-parallel combinations. The top speed of this class of locomotive was 100 km/h.

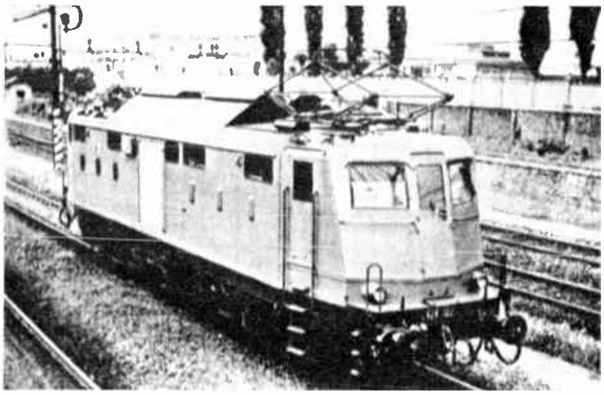
Two later classes of dc locomotives, E 326 and E 428 (Fig. 11), were built between 1930 and 1934. Each weighed more than 135 tonnes and had a top speed of 130 km/h, thereby making them the largest and fastest locomotives built up to that time. Rated at 2800 kW, the E 428s had eight motors, which could be operated in the following combinations: all eight coupled in series; series-parallel, eight motors coupled in two groups of four motors, each in series; parallel, eight motors coupled in four groups of two motors, each in series.

The E 428s became the prevalent class of fast passenger service on a number of pre-World War II dc installations (including the Pisa–Florence–Faenze line). Two other classes of Breda-built locomotives, the articulated E 636 and the semistreamlined E 424 (Fig. 12), were the last to be built at the end of the second phase of Italian electrification (1940–1943).

Three phase + dc + third rail = a big mess

By the late 1930s, the Italian Ministry of Transport—and the traveling public—awoke to some of the fantastic problems and major inconveniences that had developed under three discrete, and incompatible, electrification systems installed since 1900. For example, in traveling from Rome to Milan, a train would have to change from an overhead, single-wire conductor dc locomotive to one equipped for three-phase, two-wire service. On some lines, the transition was from third-rail to overhead dc to three-phase power.

FIGURE 12. Semistreamlined wartime class E 424 locomotive, built in 1943 for high-speed passenger service on the Italian State Railways.



Obviously, these heterogeneous systems were impractical, costly, complicated, and time-consuming in both operation and maintenance. There could be no standardization of traction equipment, and separate repair shops and spare parts had to be maintained. There was even a serious problem in the training of enginemen to handle this mixed equipment.

In 1939, the ministry decided that all electric lines should be converted to a standardized 3000-volt, dc single-wire overhead trolley system. The vast conversion effort had hardly begun when Italy, in June 1940, found itself directly involved in World War II.

The war damage sustained by the FS from aerial bombardment and ground action was huge: 5000 route-kilometers (89 percent) of electrified lines and 10 800 km of overhead contact wires (90 percent of total) were either completely destroyed or put out of service. Of the vast FS electric traction fleet, 313 three-phase ac locomotives and 523 dc engines were badly damaged; 86 ac engines and 18 dc locomotives were ruined beyond repair. More than 80 percent of passenger cars and freight vans were a total loss.

The war compelled the FS to rebuild as a unified and standardized national system, with universally compatible locomotion units. It also sounded "taps" for most of the remaining steam service still in mainline use.

The postwar period, the present—and the future

In the third phase of Italian railway electrification (1945–1950), the FS undertook the herculean task of reconstructing virtually the entire internal railway system. Most of the remaining three-phase and third-rail lines were dismantled and replaced by the single-wire dc catenaries. War-damaged locomotives were rebuilt and all traction equipment was converted for dc use. As the financial and economic conditions of the country improved, the lines on which construction had started before the war were redesigned and completed in accordance with the unified specifications.

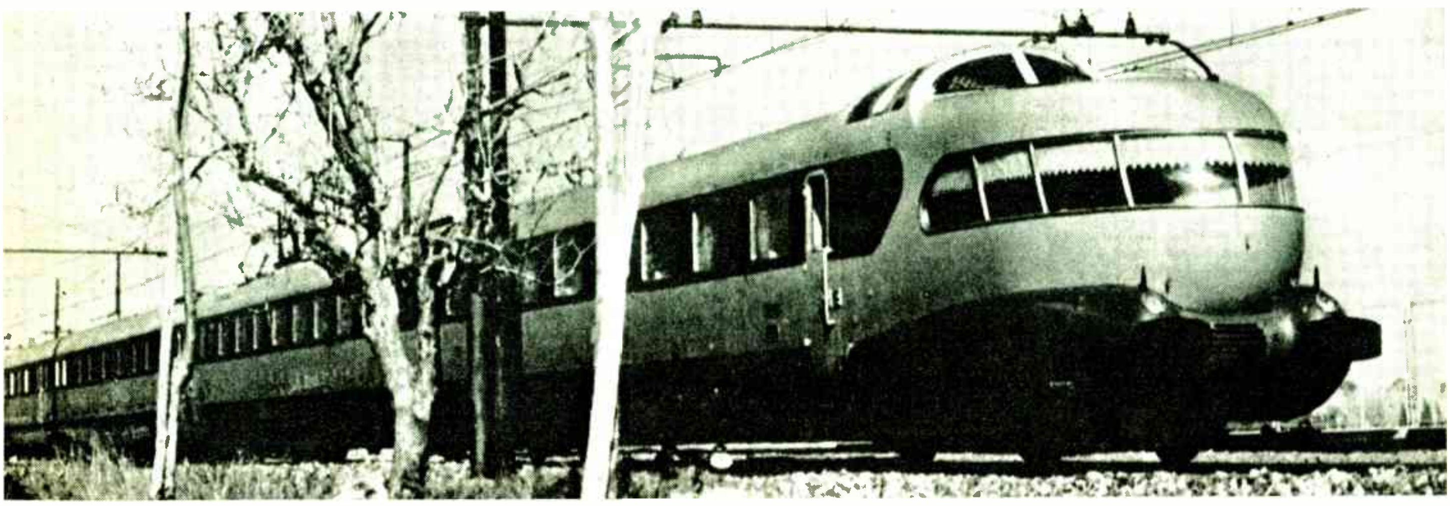
In 1958, the FS embarked upon a series of long-range programs for improving and modernizing the electrical network, its rolling stock, and traction units. During the period from 1958 to 1962, all mainline steam traction was replaced either by all-electric or diesel electric locomotives. The second phase of the far-reaching FS modernization scheme is the current Ten-Year Plan (1962–1972), in which rolling stock, automatic coupling techniques, and traction equipment are being greatly improved. A new class of electric locomotive (E 444) has a maximum speed of 180 km/h. Containing four dc motors, with a total rating of 3000 kW, each engine is capable of exerting a maximum drawbar pull of 50 000 kg at top speed. Rheostat-controlled dynamic braking is one of the features of this latest group of electric locomotives.

Over the next four years, the electrical network will be strengthened by the electrification of a number of branch and secondary lines, and by the incorporation of automatic safety devices throughout the FS system. Figure 13 shows the status of the FS network as of January 1, 1965.

It is beyond the space limitations of this article to include descriptions of the remarkable *elettromotrici* and *elettrotreni* (motorcars and multiple units) or the ultra-modern *automotrici* (diesel-electric locomotives and

FIGURE 13. Map showing the extent of the Italian State Railways' electrified network as of January 1, 1965.

FIGURE 14. The ultramodern, high-speed articulated elec tric train "Settebello," which, with its running mate, "Arlecchino," is typical of the deluxe passenger service available on the Naples–Rome–Milan mainline run.



diesel-electric propelled articulated units) that are used extensively for high-speed deluxe passenger service on the Naples-Rome-Florence-Milan runs and in international operation. Suffice it to say that the FS is generally regarded in international railroad circles as the finest railway system in Europe. Figure 14 is a view of the "Settebello," one of the latest and most unusual express trains in the FS fleet.

Hungarian railway electrification[3]

This part of the story must inevitably refer back to the pioneer work of Dr. Kandò and its interrelationship with the original three-phase system he designed for Italy. Although we may think of present-day Hungary as a small, middle-European country oriented to the political bloc of Eastern Europe, one must remember that the Austro-Hungarian Empire of the pre-World War I era was a sizable Central European power whose geographic boundaries extended from its border with Germany, Switzerland, and Italy to the Turkish frontier. Austria-Hungary at that time included what is today Czechoslovakia, Yugoslavia, and the Italian province of Trentino. Thus the potential scope of a long-range railway electrification program was rather vast.

No three-phase for Hungary. After Kandò had designed the radically different three-phase system for the Valtellinese lines in Italy, a logical question ensued: Why was this system not adopted in Hungary? Kandò reasoned that, although the Italian system solved the problem of mainline electrification in heavy-grade Alpine territory negotiated by light and powerful locomotives, the 15-Hz (later 16.7-Hz) current was not compatible to integration into a standard utility network without the construction of many expensive frequency-changer substations. In short, he was intent upon developing a single-phase, 50-Hz railway electrification scheme that could be integrated into the existing three-phase 50-Hz utility system.

Kandò's original plan was threefold:

1. To divide the Austro-Hungarian railway system into three equal load sections, and to feed each of these by one phase of the three-phase utility network (Fig. 15).

2. To use a Kandò-designed phase converter installed aboard each locomotive (series-commutator motors had

not yet been developed) for the purpose of converting single phase 16 000-volt contact-wire energy to polyphase at approximately 1000 volts, which would then be fed to polyphase 50-Hz induction-type traction motors.

3. To employ polyphase, asynchronous slip-ring traction motors that were adaptable to speed-change settings by varying the number of poles and the intermediate steps with a resistor connected to the secondary taps. (Control was also to be designed for a unity power factor and maximum efficiency at all load conditions.)

Variable-voltage drive and the phase converter

Kandò's three bold objectives established the parameters of his overall scheme and stipulated the required hardware for solving some of the existing technical problems. Although he could have solved some of his motor-to-wheel speed ratio problems mechanically (by means of reduction gears), he preferred to evolve an electrical solution.

For example, the usual large drive wheels of electric locomotives could only be coupled to the direct drive of induction motors having a rather low rotational speed. A low-speed 50-Hz motor needs many poles. This requirement, combined with the relatively small rotor diameter of motors that can be installed in the limited space available on locomotives, makes the pole pitch small. Therefore, to get an induction motor with good operating characteristics over a large range of power and speed, Kandò abandoned the conventional method of feeding the induction motor with a constant voltage and, instead, varied the voltage in proportion to the square root of the power output of the motor. This involved the installation of a synchronous motor generator aboard the locomotive, in which the single-phase motor was fed from the single-phase voltage from the contact wire; and since its polyphase generator had a variable excitation, the required variable polyphase voltage was provided for the induction motor. Also, by regulating the dc excitation voltage, the synchronous machine could run with a unity power factor.

Kandò then incorporated a phase converter into the design of his basic synchronous machine. This combination produced a four-pole synchronous machine in which the rotor was excited by direct current in the conventional way. The stator carried two windings, one of which was a polyphase winding and the other a single-phase winding (see Fig. 16 diagram).

Other advanced design details of the Kandò traction system included the internal cooling of the stator by oil and the cooling of the rotor by water.

Delay, disappointment—and World War I

Bold and ambitious engineering schemes required a similar degree of financial support even in Austria-Hungary. Although Kandò's firm (Ganz Company), plus one of the largest private banks and an affiliated rubber company, were willing to contribute their support to the electrification venture, the bulk of the financing had to come from the government. Unfortunately, the 19th century-oriented Austro-Hungarian Empire of Franz-Josef was more interested in the state of the art galleries than in the latest technologies. Further, the increasing political tensions of the pre-World War I period were fast culminating into crisis proportions, and the production of armaments took priority over the building of railroads.

Under the terms of the Triple Entente, Germany, Austria-Hungary, and Italy were pledged to cooperate as allies in the event of war in Europe. The rest is history: August 1914 saw Germany and Austria-Hungary at war against Russia in the east and against France and Great Britain in the west. For about a year, Italy

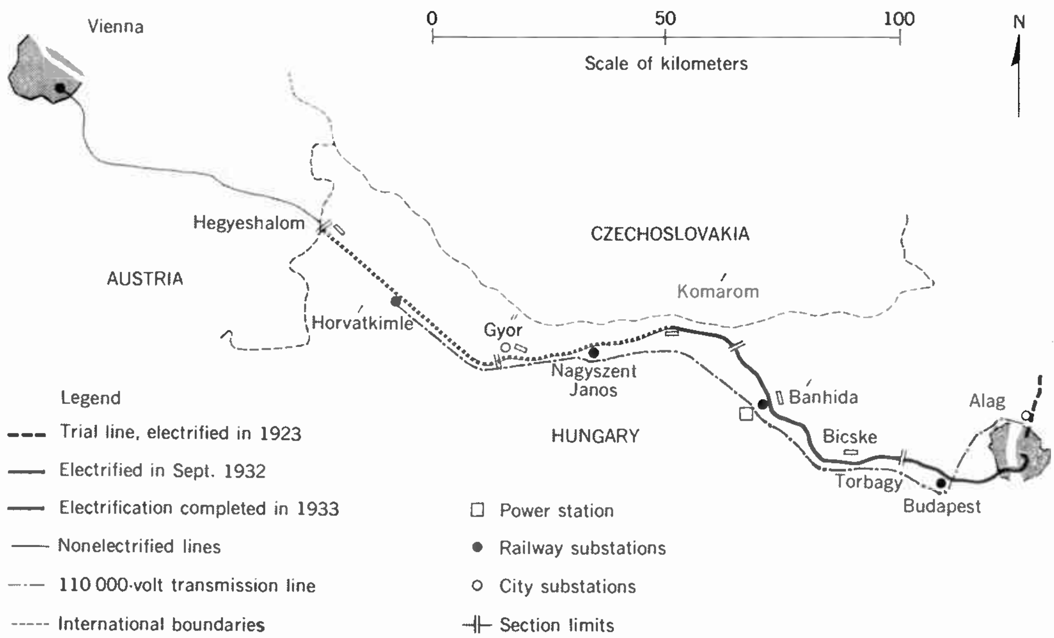


FIGURE 15. Map of the Hungarian electrified rail line from Budapest to the Austrian border. The line continues to Vienna under control of the Austrian government. Note that the load section limits, originally in Kandò's design scheme, are indicated.

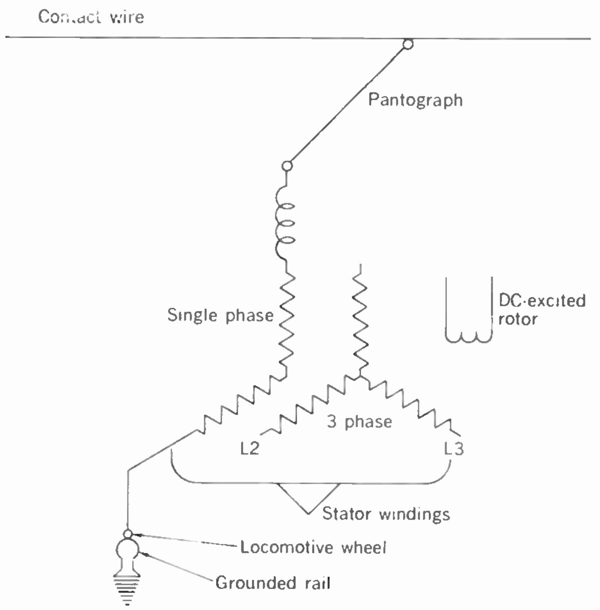


FIGURE 16. Fundamental circuit diagram of the Kandò phase converter, developed prior to World War I.

remained neutral; then, succumbing to the territorial promises made by British diplomats, Italy, in a move that infuriated Austria-Hungary, entered the war on the side of the Allied powers. Ironically, the former good neighbors who had cooperated closely on railroad engineering projects, such as the three-phase electrification of the Italian alpine system, now faced each other as enemies along a jagged 500-km mountain front from the Dolomites to the Julian Alps. Following the three disastrous battles of the Isonzo in 1916–1917, the Austro-Hungarian armies made good use of Italy's northeastern rail lines in pursuing the fleeing Italian forces beyond the River Piave.

But with the ultimate defeat of the Central powers in 1918, the Austro-Hungarian Empire was subdivided into the autonomous, artificially created nations that are shown on the current political maps of Central Europe. Hungary lost two thirds of its territory, 60 percent of its coal mines, all of its natural gas resources, and 95 percent of its hydroelectric potential.

Electrification proceeds in Hungary: 1915–1933

Despite the hazards and uncertainties of World War I, Kandò resumed work on his scheme in 1915, and an experimental locomotive, incorporating Kandò's advanced traction motor designs, was built at the end of the war in 1918. Although this experimental engine performed well during many years of tests and subsequent design modifications, it was not until November 1928 that Hungary recovered economically to a degree that would permit the electrification of the Budapest–Vienna mainline (Fig. 15). Even then, Hungary was unable to raise the entire capital needed for the electrification of its 190-km-long portion from Budapest to the Austrian border. However, the report on the excellent performance of the Hungarian experimental locomotive, delivered at the First World Energy Conference in 1929, persuaded the British government to provide the additional financial assistance. As a condition of this deal, a part of the locomotive equipment construction order was placed with British manufacturers (Metropolitan-Vickers Electrical Company and The English Electric Company), acting in the capacity of subcontractors to the Hungarian Ganz Company.

To supply the electric energy required for the initial division of the line, a 100-MW steam-electric station, utilizing a low-grade slate coal, was completed by 1931. Passenger service on the 105-km-long Budapest–Komàrom section, with four, 93-tonne locomotives (each rated at 1650 kW) of the type shown in Fig. 17, was inaugurated on September 12, 1932. (An inboard profile of this type of engine, featuring the Kandò "mechanical triangle" drive that was standard on most Italian locomotives for many years, is shown in Fig. 9.) In 1933, the 192-km-long section from Komàrom to the Austrian border was completed, and 22 additional locomotives were ordered. In all, 29 passenger- and three freight-service locomotives served on the Budapest–Vienna line until the Russian occupation in 1944. A total of 600 track-kilometers was equipped with 16 000-volt overhead contact wires.

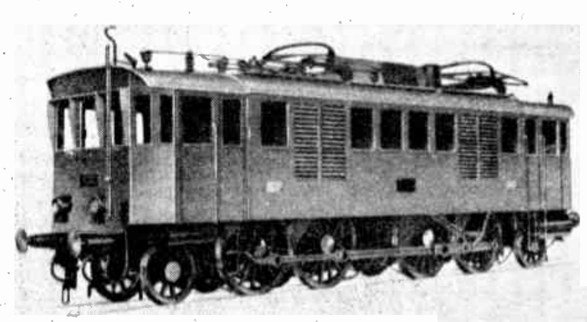
Although the Hungarian State Railway electrification is insignificant by comparison with other European electrified networks, the pioneer work done by Kandò had great influence on the electrification programs and locomotive designs of a number of European systems.

British Railways[1]

The railway systems in Great Britain, much like the early Italian lines, began as privately operated ventures that were ultimately consolidated by transferral to government operation.

Liverpool Overhead Railway. This 11-km-long line, which was completely electrified by December 1896, was the world's first electrically operated elevated railway. The original rolling stock consisted of 22 two-car units. Each unit was equipped with two 45-kW motors and direct series-parallel control. Because of the inherent low-speed capability of the propulsion equipment, these cars were replaced in the early 1900s by three-car, permanently coupled articulated units (two motorcars, one trailer). Each motorcar was fitted with two Dick, Kerr 75-kW completely enclosed motors, with series-parallel control. Both sets of motors on the three-car units were operated by a controller at each end of the train. Further equipment modernization has taken

FIGURE 17. A typical passenger locomotive of the type used on the Hungarian State Railway for the Budapest–Vienna Service. The inboard profile of this engine, showing the "mechanical triangle" drive, is shown in Fig. 9.



place regularly up to the present time. The rolling stock now in use consists of 38 motorcars and 19 trailers permanently coupled in three-car units.

Electric energy for the line is supplied by a public utility through three railroad substations. Third-rail conductors carry 500-volt direct current that is picked up by overruning contact shoes. The line resembles the Chicago Transit Authority's "loop" elevated system in that its primary function is to transport intracity passengers between residential areas and center city.

Lancashire and Yorkshire Railway. The electrification of the Liverpool–Southport section of this line, in 1904, was the first example of a complete changeover to electric traction of a mainline railway section in Great Britain. The entire electrification, undertaken by Dick, Kerr & Co. Ltd., extends 83 route-miles (133 km).

The power plant, at Formby, was originally equipped with four 1500-kW generators, driven by cross-compound (Corliss) reciprocating engines, and one 4000-kW turboalternator set to generate the 7500-volt 3-phase 25-Hz current carried over the transmission line. Current was converted at four substations by means of 600-kW rotary converter sets and supplied to the side-contact third-rail conductor at 600 volts dc. The reciprocating engines were replaced by steam turbines in 1927.

The original generating equipment continued in operation for more than 40 years, but because of the increased service demands and the need for higher-speed rolling stock, the substation equipment was replaced and the main power supply is now obtained at 50 Hz from the National Grid. Figure 18 shows the Southport substation in which four of the original rotary converters were installed in 1904.

The original trains consisted of four to seven coaches, with the motor-powered cars at either end (Fig. 19). Each motorcar had four 112-kW self-ventilated motors (for a total rating of about 900 kW per train), equipped with single-reduction-gear drives. Additional, improved multiple-unit equipment was added to the line from 1921 to 1939, when World War II forced an interruption in the rolling stock replacement program. Figure 20 shows a typical present-day five-car train on this line. The end coaches are motorcars, each of which contains four 175-kW forced-air-cooled 600-volt motors. These trains have an acceleration rate of 0.6 m/s^2 and a maximum speed of 112 km/h.

This rail line (now British Railways, London Midland Region) has two other electrified (catenary) branches: Heysham, Morecambe & Lancaster, utilizing multiple-unit cars that operate on a 6600-volt, 25-Hz single-phase trolley; and Bury–Holcombe Brook, operating from a 4000-volt dc wire. The lines total 26 route-miles (42 km).

An unusual third-rail electrification is the 22-route-mile (35-km) Manchester–Bury branch of the London Midland Region system. Inaugurated in 1915, the line carries 1200 volts dc through side-running conductors. The third rail is wood-protected on one side and on top. Contact is made by a spring-loaded steel shoe affixed to

FIGURE 18. View of the Southport substation, built in 1904 for the Lancashire and Yorkshire Railway electrification, showing the four 600-kW rotary converters.

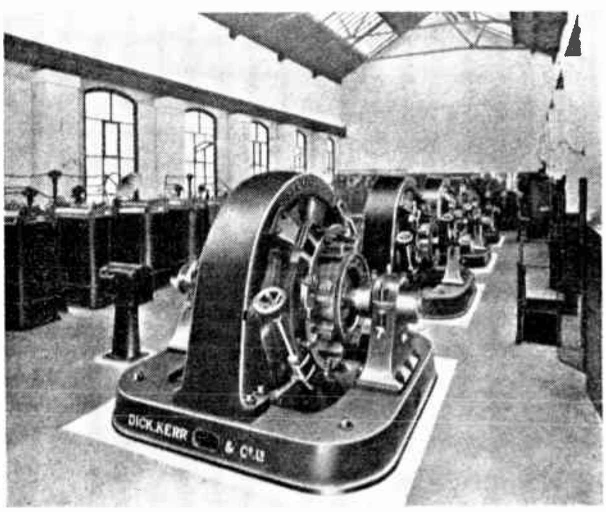


FIGURE 19. One of the original electric trains, placed in service in 1904, on the Liverpool–Southport branch of the Lancashire and Yorkshire Railway.

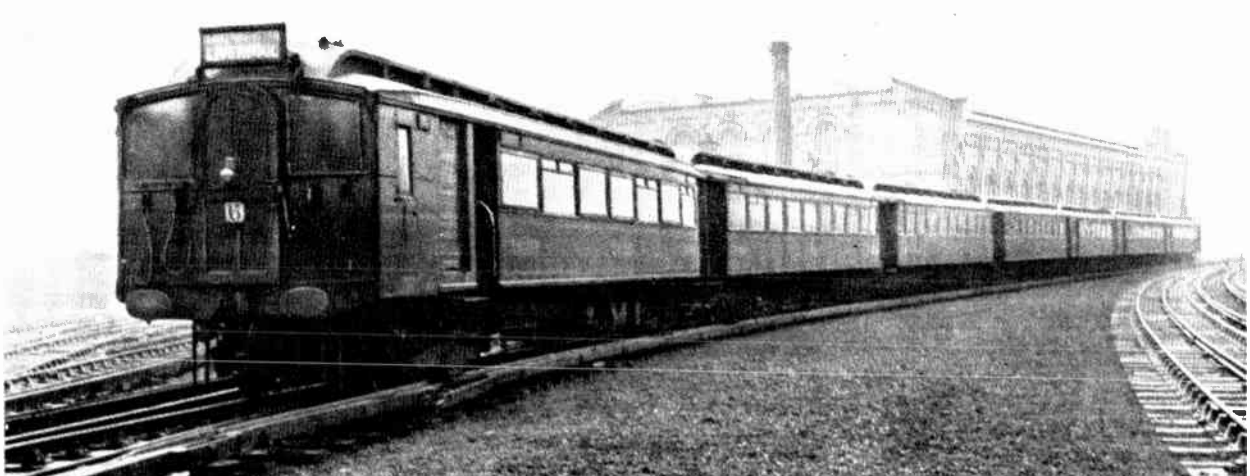


FIGURE 20. A present-day five-car multiple-unit train on the Liverpool–Southport electrification of British Railways.

FIGURE 21. Photo, taken in 1915, shows a five-car multiple unit on the Manchester–Bury branch of the Lancashire and Yorkshire Railway. The trains collected current from an unusual 1200-volt dc side-contact third-rail conductor.

the axle boxes of the rolling stock. A typical five-car multiple unit (Fig. 21) is composed of three motorcars and two trailers. The power units of each motorcar are rated at a total of 600 kW.

The power supply was originally obtained from a specially built generating station at Clifton. It was equipped with two 5000-kW, 6600-volt, 25-Hz turbogenerators, and the current was converted to 1200 volts dc in two substations, each equipped with three 1000-kW rotary converters.

North Eastern Railway (British Railways, North Eastern Region). The 1500-volt dc electrification of the 18-route-mile (29-km) Newport–Shildon section was particularly noteworthy since it was the first English mainline (1915) on which electric locomotives (Fig. 22) were used in freight service. It was essentially a coal haul from the collieries in southwest County Durham to the iron works in the Middlesbrough area. The overhead system consisted of two hard-drawn *4/0* copper conductors. The contact wires were supported from a steel auxiliary catenary, which in turn were suspended from the main steel messenger cable. Double insulators carried the main catenary from the steel supporting structures.

The ten 80-tonne double-truck steeple-cab locomotives were each equipped with four forced-air-cooled suspended motors, rated at 200 kW apiece. Each pair of motors was permanently connected in series. Power was transmitted to the drive wheels by means of single-reduction gears. The engines had unit-switch-type control gear with electromagnetically operated contactors. Current was collected by two air-operated double-pan pantographs. Controllers were located at either end of the central cab.

Both the catenary and the locomotive construction were handled by Siemen Bros. Dynamo Works Ltd. The locomotives remained in operation until 1935, when a sharp drop in traffic requirements forced the discontinuation of the service.

Other mainline and suburban electrification. Table I lists the significant details of two other major electrified systems in the British Railways network that have been in service for many years.

Although diesel-electric traction in Great Britain—as in the United States—has been employed more extensively than all-electric locomotion on long-distance mainline service in the post-World War II period, the advent of the National Grid (network of public utilities), and the ever-increasing construction of nuclear generating plants, has given renewed impetus to the further electrification of British Railways. At the present time, several schemes for the extensive electrification of a number of mainline and suburban routes out of London and the principal cities in England and Scotland either have been completed or are presently under construction.

For example, electrification of the 150-route-mile (240-km) London–Southampton–Bournemouth rail line was completed in March 1967, and full electric services were inaugurated on July 10. On this new line "push–pull" locomotion will be used for the first time. In this operation, 12-car express trains will be propelled from behind in one direction, and hauled in the other—at

I. Two major interurban electrified lines in England

Line	Route	Length, route-km	Initial Service, year	Type of Service	Conductor	Energy	Rolling Stock
British Railways:							
Eastern Region	London–Shenfield	40	1949	passenger	catenary	1500-volt dc	multiple units
Southern Region	London–South Coast	150	1909	passenger freight	third-rail	660-volt dc	multiple units locomotives

speeds up to 144 km/h—by four-car electromotive power units, rated at 2300 kW. Conventional multiple-unit cars are used to provide the local and intermediate suburban services. The third-rail conductor carries direct current at 750 volts.

The electrification of 37 route-miles (60 km) of suburban railway, running from Glasgow to the coastal towns of Gourock and Wemyss Bay, was completed in February 1967. The catenary system utilizes single-phase alternating current at the industrial frequency of 50 Hz.

Electrified systems in other European countries[4]

In the limited space of this final installment, it would be impossible for the writer to do adequate justice in describing all of the great electrification systems on the European continent. Therefore, we shall present but a bare historic outline of these developments from the early days of the 20th century to the present time, plus a brief excursion into the future.

By 1906, a number of electrified lines were operating in various countries throughout Europe and a start was made on major electrification schemes. Of these, the most extensive was in Switzerland, where large-scale national electrification began in 1918. The ready availability of hydroelectric power was, of course, a major incentive in that country. Sweden, Norway, Austria, and Germany electrified some main lines in the 1920s. All of these countries used 15 000-volt 16.7-Hz single-phase alternating current.

The use of overhead conductor wire was almost universal (except for some suburban and main lines in England, and a limited amount of trackage in Italy). By 1930, almost all of Europe could boast of some electrified rail lines.

Present and future projects, locomotion equipments, and rolling stock

Swiss Federal Railways. A new class of electric locomotive, designated RE 4/411, has been developed for the Swiss system. It is designed to operate in single units for hauling heavy passenger and fast freight trains on level stretches, and in two-unit combinations over heavy-grade mountain sections. These engines are rated at 4700 kW each, and their maximum speed is 140 km/h.

The present Swiss railway power supply is 15 000 volts, single-phase alternating current, at 16.7 Hz.

French National Railways (S.N.C.F.F.). As of January 1, 1967, the S.N.C.F.F. had 5321 route-miles (8600 km) of electrified lines, over which 72.5 percent of all passenger and freight traffic was carried. Current plans include the acquisition of 21 new dc locomotives, 20 dual-voltage

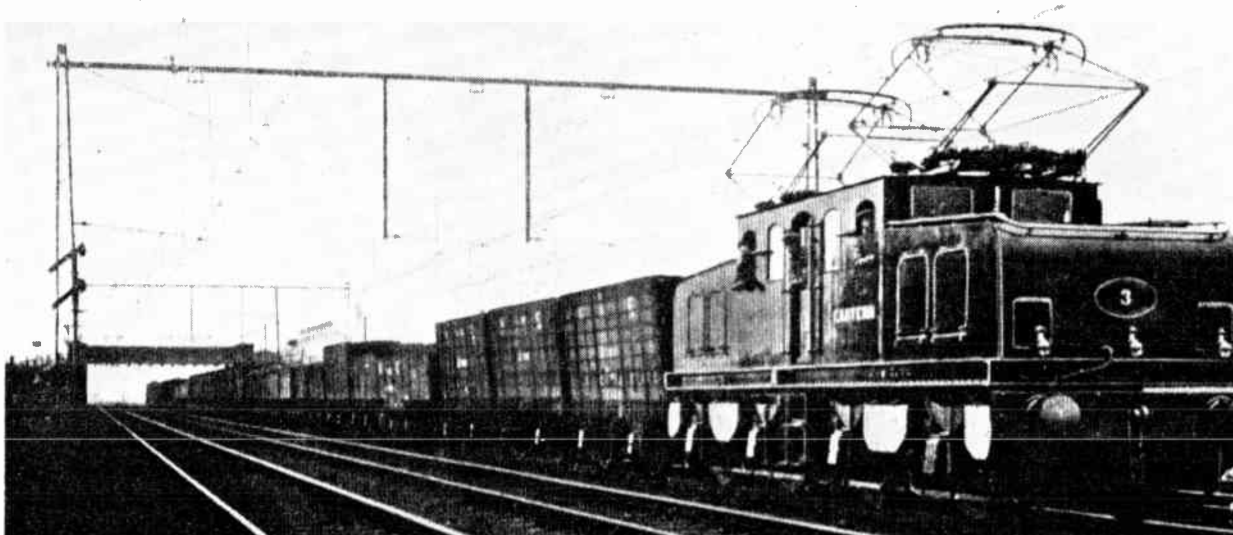


FIGURE 22. An 80-tonne steeple-cab Siemens-built locomotive, rated at 800 kW, hauling a coal train on the Newport-Shildon electrification. This view, taken in 1916, clearly shows the unique overhead construction in which an auxiliary catenary wire is used in conjunction with the main catenary cable.

(3000, 25 000, for international service) locomotives, and the eventual replacement of old traction units and rolling stock.

Belgian National Railways. Eight new quadricurrent locomotives for this system haul the Trans-European Express trains on 25 000-volt 50-Hz energy in France, 3000-volt direct current in Belgium, 15 000-volt 16.7-Hz alternating current in Germany, and 1500-volt direct current in Holland.

Norwegian State Railway. This road has recently placed six silicon-rectifier locomotives, rated at 5500 kW each, in the heavy ore-hauling traffic in northern Norway and Sweden, where operating conditions and grades are unusually severe. The engines, among the most powerful all-electrics in the world, are coupled in pairs for this rugged duty.

Soviet Railways. Russia's 400-route-mile (640-km) Abakan–Taisket electrified line was placed in operation last year. The trackage forms the easternmost section of the south Siberian main line. Winter temperatures there reach as low as −57°C, and the snow cover ranges from two to three meters. The trolley voltage is 25 000 volts at 50 Hz.

German Federal Railway. Three additional electrified branch lines, totaling 193 route-miles (310 km), were placed in service last winter, thereby increasing Germany's overall electrification to 4325 route-miles (7000 km). At the present time, plans for the electrification of the Black Forest (Schwartzwald) Railway are being considered.

Swedish State Railway. This rail system is now receiving delivery of 20 thyristor locomotives that represent the first application of this electronic device on electric traction equipment taking energy from conductors carrying 15 000 volts at 16.7 Hz. Initial performance reports indicate very smooth acceleration characteristics in passenger train operation. Each locomotive is rated at 3700 kW. The engines are geared for a top speed of 135 km/h.

Czechoslovakia State Railways. For the past several years, the Czech government has sponsored an intensive electrification program in which 25 000-volt 50-Hz energy is carried on overhead trolley conductors. The new rolling stock consists of six-car, articulated multiple units (alternate motor and trailer cars) for the shorter mainline and suburban passenger runs. These units reportedly have a top speed of 160 km/h. Electric locomotives are used on the long-distance passenger and freight hauls.

Finnish State Railways. Thirty electric train (two-car-unit) sets will soon be installed on the Helsinki–Kirkkonummi and Helsinki–Riihimäki lines. Their average speed will be 50 km/h, and maximum speed will be 120 km/h.

In the final news items from abroad, we have learned that

1. The Danish State Railways has ordered 75 two-car units to improve and extend electrified suburban service in the Copenhagen area.

2. The Hellenic States (Greek) Railway has placed an order for nine multiple-unit articulated train sets for use on the high-speed Piraeus–Athens–Kifissia lines.

3. The Austrian Railways is electrifying the lines on the Amstten–Selzthal, Klein Peifling–St. Valentin, and Hieflan–Eisenerz routes.

Dr. Kálmán Kandó was born in Hungary in 1869, and received his engineering degrees in mechanical and electrical engineering from the University of Budapest in 1892. In 1893 he went to France, where he worked as an electrical engineer for the Compagnie des Fives-Lille. Here he developed a novel mathematical approach to the design of three-phase induction motors.

In 1896 Kandó returned to Hungary in the employ of the Ganz Company. In this capacity, he experimented extensively with the application of the three-phase motor for railway traction. He was sent to the United States in 1897 to study the electrification of the B&O Belt Line system in Baltimore. This assignment made him realize that the low-voltage dc system was unsatisfactory for mainline systems, and led to his development of the phase converter that bears his name. His notable work on the Valtellinesi lines and the Hungarian State Railways is covered in the text of this article.

Kandó also served as a consultant to George Westinghouse; he held more than 138 patents in countries throughout the world, including four in the United States. Kandó died in 1931—two years before the completion of the Vienna–Budapest line.

4. The Roumanian State Railway has electrified its first main line from Brasov to Ploesti with a 25 000-volt, 50-Hz overhead system.

In summary . . .

It is apparent that the European railway systems have implemented their mainline electrification schemes to a far greater degree than that which has been done in the United States. In all fairness, however, the parameters for comparison are quite different. First, the geographic areas of most European countries are considerably smaller than in the U.S., thereby reducing energy transmission problems—and costs. And in many of these countries, cheap hydro power is available from alpine regions.

Because of the generally smaller size of European states, internal distances—and, hence, travel time required—are usually less than those in the U.S. Thus the competitive edge of air travel abroad is diminished. Finally, two other salient factors favor rail lines abroad: By comparison with the United States, fewer Europeans, per 1000 population, own motorcars; and rail travel has been traditionally popular on the Continent for many years, primarily because of the three classes of service available to the public.

But as we have seen in this trilogy, economic and technical factors seem to give the green light to the extension of railway electrification in both the United States and Europe. Thus the short-term outlook (next five ten years) is bright.

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Nuclear test instrumentation with miniature superconductive cables

For underground nuclear testing, superconductive cables offer a promising alternative to presently used cables in that dramatic improvements in bandwidth are possible without significant increases in cost

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The instrumentation requirements for nuclear testing are particularly stringent because of the nature of the transients involved and because of the distance at which instrumentation must be placed. Presently used high-quality transmission lines are not capable of nanosecond performance where cable runs of approximately 1000 meters are concerned. Experimental data from the U.S. Atomic Energy Commission's Nevada Test Site show that 30-ns rise times are attainable for a superconductive cable 7620 meters long. Although the performance of conventional cables (normal conductors) can be improved by low-temperature operation, superconductive cables operated at the same temperature offer bandwidths 100 times greater.

In an underground nuclear test, measurements of a number of transient phenomena are desired. The parameters of the cables (materials, geometry, and permissible length) that connect transducers to recording equipment are dictated by the required system bandwidth. Reducing cable costs while maintaining bandwidth can prescribe the physical arrangement of the recording trailers. Each underground test involves cabling costs of several hundred thousand dollars. It will be demonstrated in this article that miniature superconducting coaxial cables possessing enhanced bandwidths may be used at costs comparable to those of currently employed methods.

The bandwidth requirements for various types of nuclear test measurements are given in Table I. Diagnostic instrumentation of the light or gamma radiation from the detonation itself constitutes the broadest band requirement. Test instrumentation is installed in trailers stationed at a remote location from the detonation point. Because of the large number of participants in each test, there are typically from 10 to 40 trailers, each of which requires 10 to 20 cables. These long cables between transducers and recording equipment limit the bandwidth of the instrumentation system. This limitation is kept at a minimum by placing the trailers at the nearest radial point from the detonation permitted by safety considerations. Figure 1 is an aerial view of the test setup for a typical test.

Signal deterioration (reduction of bandwidth or increase in rise time) stems from increased cable attenuation at high frequencies as the result of skin effect, dielectric losses, and radiative losses. Present capability of achieving nanosecond performance is limited by impractically large cable diameters. A cable 6 inches (15 cm) in diameter is required, for example, to achieve a 0–50-percent step response of 6 nanoseconds for a cable run of about 430 meters. The frequency response of the components of the

I. Present instrumentation system at Nevada Test Site

Transient	Transducer	Required Frequency Response	Cable
Gamma or light from detonation	Compton diode	100 MHz–1000 MHz	7.6-cm air dielectric or 2.2-cm Styroflex/1.3-cm Foamflex with compensation
Pressure		10 MHz–100 MHz	1.3-cm Foamflex or RG213 with compensation
Temperature	thermocouple	1 kHz–10 kHz	twisted shielded pair
Control, timing, etc.		10 kHz–400 kHz	twinax or twisted shielded pair

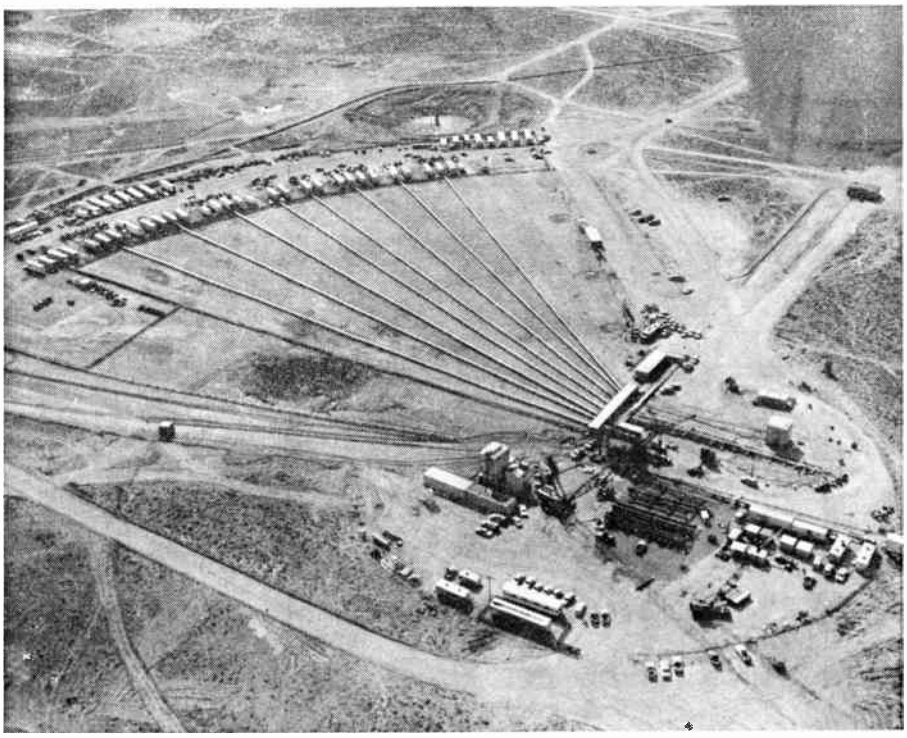


FIGURE 1. Aerial photograph of typical nuclear instrumentation at Nevada Test Site. Transducers are in right foreground, instrumentation trailers in left background. Length of cables is about 300 meters. (UCLRL-NTS photo)

instrumentation system must be compatible. Instrumentation for the highest-speed transients requires that bandwidth transducers and recording equipment operating in the gigahertz region be linked to gigahertz bandwidth coaxial cable.

Two techniques are currently employed to satisfy instrumentation requirements at the Nevada Test Site. On one hand, a large-diameter cable giving the desired frequency response may be used. Such cable is expensive: 8-cm Styroflex, for example, costs about $18 per meter exclusive of installation. On the other hand, smaller-diameter cables, such as 1.3-cm Foamflex or 2.2-cm Styroflex, may be used with compensation to give broadband response. In this case, the compensation network (or equalizer) attenuates the low-frequency components of the signal to provide compatibility with the frequency response of the system, but only at the cost of sacrificing signal amplitude and making the signal more subject to masking by noise.

Experiments during the past ten years have shown that miniature superconductive cables produce very little attenuation at frequencies from dc to many gigahertz. For instance, experiments conducted by Nahman and Gooch[1] in 1960 indicated an attenuation of 52 dB/km at 8 GHz for a superconductive coaxial line with a niobium center conductor 0.25 mm in diameter, a Teflon dielectric, and a lead outer conductor with a 0.86-mm inner diameter and a 2.4-mm outer diameter. This measurement was confirmed in 1964 by Nahman and Allen,[2] who also demonstrated that the dielectric loss tangent decreases significantly at low temperatures. Cummings and Wilson[3] demonstrated that miniature superconductive cable is capable of transmitting high-voltage pulses of up to 12 kV. They have also measured a step response of 0.39 nanosecond over a length of 317 meters.

The purpose of this article is to discuss the application of such cables to nuclear tests at the Nevada Test Site, where the number of broadband transmission lines makes the cost of refrigerating a long cable economically realistic. Two previously unreported aspects of miniature superconductive cables are also reported. The first is a display of pulse response after transmission in a passive system more than 160 km long. To the writers' knowledge this is the first time that a guided wave has been transmitted over this distance in a passive system.

The second is a technique for obtaining an inexpensive superconductive cable. Cable expense for a nuclear test is important because a large number of high-quality cables must be employed. Even though a miniature lead–niobium cable 2.5 mm in diameter is significantly cheaper than an equivalent high-quality Styroflex cable 7.6 to 15.2 cm in diameter, the cost is still about $4.50 per meter. However, the writers have constructed and tested an economy superconductive cable made by coating the inner and outer conductors of RG174 with lead. The pulse performance of this cable compares very favorably with that of lead–niobium cable. In addition, the lead-coated cable can be produced at a cost of about 45 to 90 cents per meter. Where large-scale applications are contemplated, further work in cable-cost reduction without sacrifice of response is dictated. The economic question then becomes one of scale: At what point does it become more economical to use superconductive cables than to use conventional Styroflex or Styrofoam cables?

The impact at the Nevada Test Site of an instrumentation system using superconductive cables would not be a purely economic one. The use of superconductive cables would be equivalent to having every instrumentation trailer served by large-diameter Styroflex, which is not currently the case. It would eliminate the network equalizers required to insure compatibility in frequency response where large-diameter Styroflex is not now used. It would

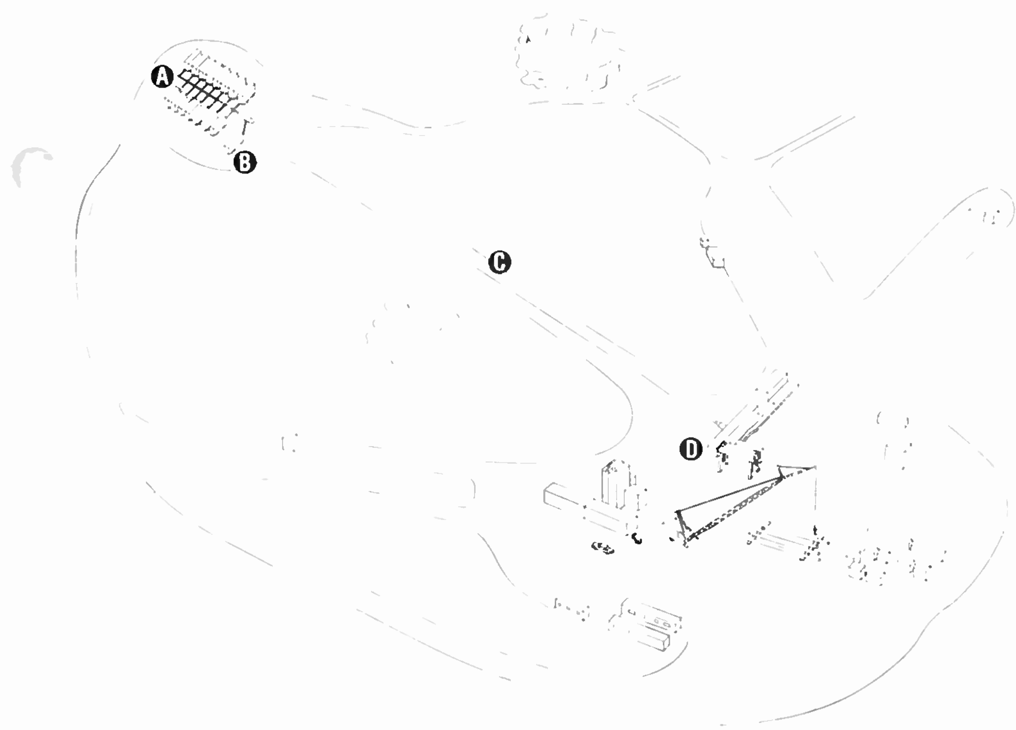


FIGURE 2. Artist's conception of nuclear test instrumentation at Nevada Test Site with miniature superconductive cables. A—Instrumentation trailers. B—Refrigerator trailer. C—Cables and pipeline. D—Transducers.

also offer the possibility of putting more wide-band channels in places where size prevents large numbers of large-diameter cables from being installed.

Tests also indicate that the miniature superconductive cable outperforms even the largest-diameter Styroflex. In addition, cable ground loops, crosstalk between cables, and distributed capacitance to ground are frequently encountered problems in long cable runs. Through the use of coaxial cables with superconductive outer conductors, the transmission paths can be well shielded against these effects, because of the flux exclusion feature and diamagnetic properties of superconductors.

Finally, each instrumentation trailer receives a strong ground shock shortly after detonation because of the proximity of the trailers to the point of explosion. For this reason, considerable effort is devoted to minimizing equipment damage through the use of special mounting devices. With a superconductive system, however, the trailers would no longer need to be located at radial points around the detonation point, but could be located in another configuration, such as that shown in Fig. 2, and at a greater distance from the detonation point.

A number of articles have appeared in the literature on the topic of superconductive power distribution systems.[4,5] Although instrumentation for nuclear testing is of a very different nature, many of the problems to be solved in implementing data transmission through superconducting coaxial cable are highly analogous. In addition, the more limited scope of this application makes it inherently more favorable for an early attempt. Data gained on the thermal performance of long, vacuum-insulated pipe would be directly applicable to power distribution systems. Finally, should superconductive power distribution become a reality, data communication channels could be added at relatively small additional cost.

Normal conductivity, superconductivity, and transmission lines

The transmission bandwidth of coaxial lines is limited primarily by attenuation in the nonzero surface impedance of the boundary.[6] An extensive discussion of boundary value solution to TEM (transverse electromagnetic) propagation may be found in Ref. 7. The noble metals (this is, silver, copper, and gold) are the best electrical conductors, and, therefore, offer the lowest surface impedance at ordinary and high temperatures.

In general, electron scattering by thermal phonons decreases, and the electron mean free path is consequently increased as the temperature is reduced in metals.

For example, the resistivity of high-purity annealed copper decreases from 1.70 microhm-cm at 295°K to 0.0308 microhm-cm at 20°K.[8] Based upon these observations, improved performance would be predicted for low-temperature operation of conventional cables. (A treatment of the temperature dependence of metal surface impedance may be found in Ref. 9.) And yet the noble metals do not rank among the 30 or so elements that under suitable circumstances can become superconducting at very low temperature. Based upon a better approximation to a perfectly conducting boundary, it would be expected that cables constructed with superconducting materials would outperform conventional cables of equivalent dimensions and the same dielectric. This fact is of importance in this particular engineering application since it sets an upper bound to the system operating temperature: As reported in the following section, an experiment was performed in which superconducting cable exhibited superior performance to conventional cables operated at low temperatures.

It should not be assumed that the superconducting surface impedance is perfect. However, since thorough discussion of the subject is beyond the scope of this article

II. Parameters of cables tested at low temperature

	RG174	RG188	Superconductive
Length, meters	213.4	81.1	213.4
Impedance, ohms	50	50	50
Inner conductor	7/0.160-mm copperweld	7/0.170-mm silver-coated copperweld	0.381-mm niobium
Dielectric diameter, mm	1.524 mm	1.524 mm	1.321 mm
Shield	. . .	38 AWG silver-coated copper	lead sheath
Dielectric jacket diameter, mm	2.667	2.794	none
Attenuation at 400 MHz and 300°K, dB/km	656	656	. . .
Type of dielectric	polyethylene	Teflon	Teflon

III. Comparison of performance of superconductive cable, RG174, and RG188

	T_0 normalized to 427 meters at 4.2°K, nanoseconds	Attenuation at 1 GHz and 4.2°K, dB/km
Superconductive cable	0.3	0.49
RG174	30	49
RG188	22.5	44.3

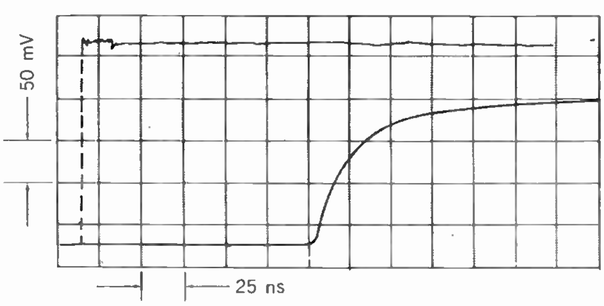
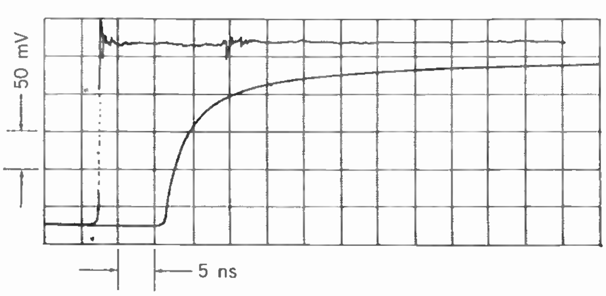


FIGURE 3. Response of RG174 cable at 4.2°K.

FIGURE 4. Response of RG188 cable at 4.2°K.



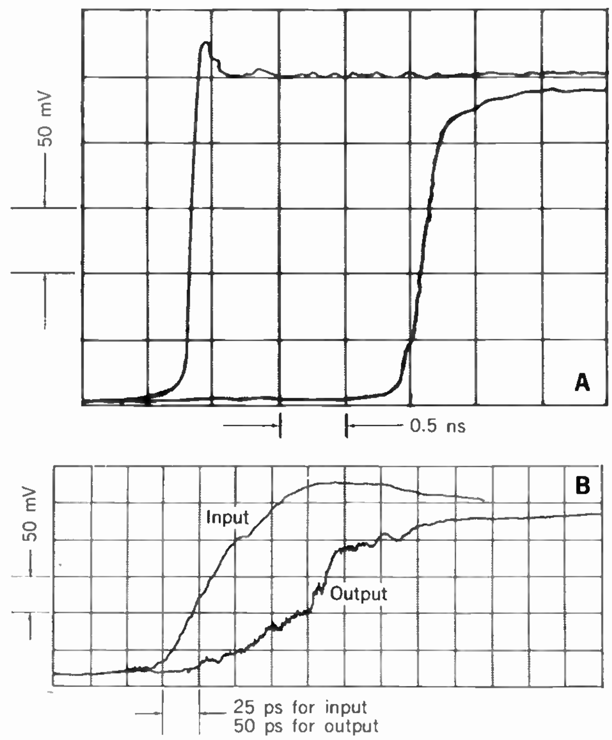
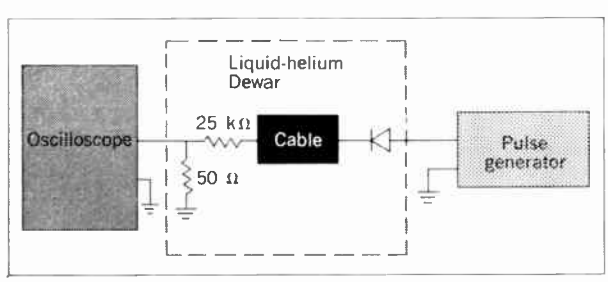


FIGURE 5. Response of superconductive cable at 4.2°K. A—Input pulse. B—Reflected pulse after transmission through 427 meters of cable.

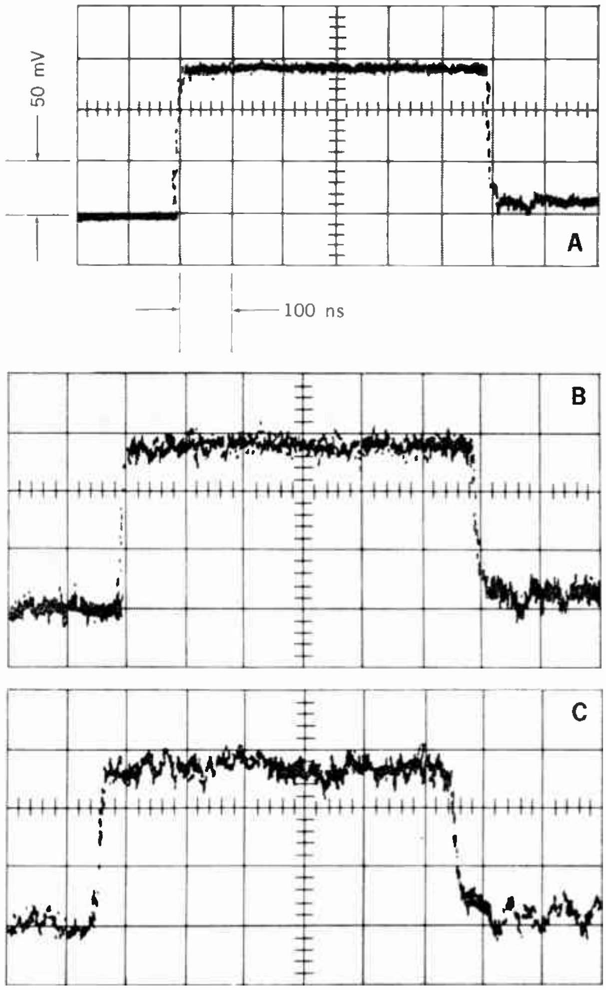
FIGURE 6. Block diagram of test setup for simulating long superconductive cable.



and since the subject does not lend itself well to a brief summary, the reader is referred to extensive treatments published elsewhere.[10–13] Modeling of the transmission characteristics of superconductive coaxial transmission lines is being pursued at the present time by the writers and others.[14]

Report of experiments

Investigations indicate that the low-loss transmission achieved with miniature superconductive cables is not obtainable with conventional cables operated at low temperatures. (The materials used in conventional cables—copper and silver—do not superconduct even at the lowest temperatures.) In one experiment, lengths of superconductive cable and of RG174 and RG188, with the cable parameters listed in Table II, were placed in boiling liquid helium at 4.2°K. An input step with a 10- to 90-percent rise time of 100 picoseconds (or 10^{-10} second) was applied to each of the cables after passing it through a sampling probe and a 1.8-meter length of RG213. The pulse traveled the length of cable under test, encountered an open circuit, and was reflected, again traveling the length of cable back to the starting point. The effective length of cable was thus double the physical length. The sampling probe had a rise time of 26 ps, and so had no discernible influence on the measurements. The 1.8-meter length of RG213 was tested, and no deterioration of the 100-ps pulse was detected.



The responses of the three cables are shown in Figs. 3 through 5 and are compared in Table III. The first column in the table gives measurements of the step response as the primary performance parameter. The value given, T_0, represents the time in which the pulse rises from zero to 50 percent of its final value. This value is a more satisfactory specification than the 10-to-90-percent rise time often used because the slope of the function representing the response of a transmission line to a step input is nearly flat at the 90-percent point.[15]

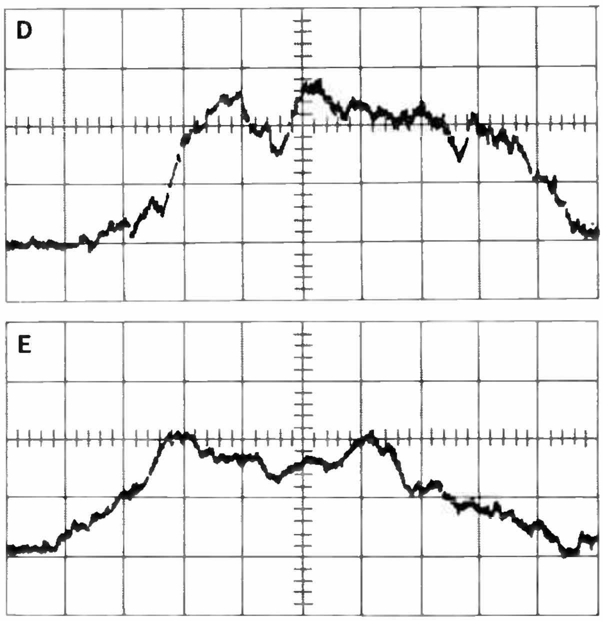
In another experiment, pulse transmission over long distances was simulated, using the 213-meter superconductive line, by recirculating a pulse about 350 times between reflecting terminations. Since no superconductive transmission line longer than 457 meters has been constructed, this experiment is of obvious value in considering the application at the Nevada Test Site. The terminations were simple impedance discontinuities at the end points of the transmission line. Figure 6 is a diagram of the experimental setup.

A pulse with a duration of about 600 ns and an amplitude of about 75 volts was used. The initial current was approximately 1.5 amperes, and the voltage seen at the 50-ohm current-viewing resistor was therefore about 150 mV. The 1N916 diode (which functioned well at liquid-helium temperatures) served as the input switch and as the impedance discontinuity for pulse reflection at the input end of the transmission line.

In the oscillographs shown in Fig. 7, the progressive deterioration of the signal may be observed. The first reflection has traveled one cable length or 213 meters; the second has traveled three cable lengths or 639 meters; and the nth, $(2n + 1) \times 213$ meters. Thus 350 recirculations represent roughly the 160-km transmission previously cited.

On each reflection a portion of the 75-volt signal is

FIGURE 7. Deterioration of pulse in simulated long superconductive cable. A—First reflection, 213 meters. B—Fifth reflection, 1920 meters. C—Tenth reflection, 4054 meters. D—Fiftieth reflection, 21 123 meters. E—One-hundredth reflection, 42 560 meters.



terminated in the resistive mismatch of the order of one minus the reflection coefficient ρ:

$$1 - \rho = \frac{2Z_0}{Z_1 + Z_0} \approx 0.004$$

or $(1 - \rho) \times 75$ volts $= 300$ mV for the first recirculation.

In addition, a small amount of the signal is terminated on each recirculation on the reverse impedance of the input diode. If the reverse impedance of the diode switch is assumed to be 100 kilohms,

$$1 - \rho = \frac{2Z_0}{Z_1 + Z_0} \approx 0.001$$

of the signal will be terminated on each recirculation; for instance, about 75 mV will be terminated on the first recirculation, taking into account the portion of the signal terminated in the resistive divider.

For any given length or distance of transmission, the response of a long cable should be equal to or better than that of a recirculator. For one thing, it is reasonable to assume that the shunt capacitance of the diode and resistors serving as terminations in the recirculating system limits bandwidth, since they terminate the signal on each recirculation. It will be observed that the background noise in the system increases progressively with each reflection. A suggested explanation is that discontinuities in the cable or terminations set up random traveling waves, which propagate between the terminations. Although a single propagation through a long cable might set up reflections at discontinuities and cause some deterioration of the waveform because of the energy extracted, the reflections should not appear in the initial ouput since they must be re-reflected and will reach the output at a later time.

Design considerations for the cryogenic environment

The problems involved in refrigerating long superconductive cables have received attention in several studies concerned with power transmission, and although refrigeration of a long cable has not yet been attempted, vacuum-jacketed lines for the transfer of liquid gases over long distances have been used in the space program.[16] The design currently being considered for the Nevada Test Site follows the general principles evolved for this and other cryogenic applications. For multiple data-transmission paths, one envisions a bundle of cables placed in a long pipe with the cryogen (helium) circulating through the pipe. The system design is complicated, since the cable superconducts only for temperatures below the transition temperature of lead, which is 7.2°K. Therefore, helium (which boils at 4.2°K at atmospheric pressure) is required as the cryogen, inasmuch as it is the only substance that maintains fluid phase (for transfer) at the temperature range in question. Because of the low temperature, it is absolutely essential to insulate the cryogen and cables thoroughly from the external environment.

Typically, insulated pipe is constructed in concentric cylinders, with the cryogenic fluid contained in the inner cylinder and an evacuated annulus between the cylinders. Thermal energy warms the center of the pipe by radiation from the external wall at 300°K, by convection through the residual gas in the vacuum jacket, and by conduction through the supports of the inner pipe. Special measures are usually taken to reduce radiation heat transfer since it varies as the fourth power of temperature. The inner pipe may be wrapped with a number of low-emissivity radiation shields (aluminum foil) separated by fibers for low thermal conductivity. This type of material is referred to as superinsulation and is evacuated to ensure low heat transfer by convection.

When superinsulation is used, the radiant heat transfer W_r is proportional to

$$\frac{T_o^4 - T_i^4}{n + 1}$$

where T_o = outer wall temperature, T_i = inner wall temperature, and n = the number of laminates of foil. In addition, the thermal load caused by conduction through the fiber or Mylar separating foil laminates and inner pipe supports must be included.

Over the temperature range 0°K through 300°K, thermal conductivity is a nonlinear function of temperature. The equation for thermal conductivity must therefore be modified as follows to take account of this nonlinearity:

$$W_c = k(T)A \frac{dT}{dx}$$

where k is the thermal conductivity, A is the cross-sectional area of the rod, and dT/dx is the thermal gradient along the rod.

Although efforts have been made to separate the radiant and conductive components,[17] in practice they are observed to interact, and it has therefore been found more useful to express both in terms of an empirical apparent mean thermal conductivity k_a as follows:

$$k_a = \frac{W \ln (r_o/r_i)}{2\pi l(T_2 - T_1)}$$

where W is the rate of heat transfer to the cold chamber, r_o and r_i are the outside and inside radii, and l is the length measured along pipe axis. The apparent mean thermal conductivities for some superinsulating materials are given in Table IV.[18] These values have been shown to be independent of pressure below 0.1 mm of mercury.

The scarcity of helium and the difficulty of liquefying it cause open-cycle operation to be very expensive. Based upon refrigeration derived from the latent heat of liquid helium, an evaporation rate of 1 liter per hour will refrigerate a thermal load of 0.75 watt. If the market price of liquid helium is taken to be \$4.00 per liter, open-cycle refrigeration costs about \$5300 per kilowatthour of operation at 4.2°K. On the other hand, closed-cycle refrigerators have been manufactured for operation below 5°K with capacities up to 1.5 kW. The cycles employed in these refrigerators are not discussed here, although there are several good references on the subject.[19–21] A closed-cycle system for refrigerating a kilowatt thermal load to 5°K costs several hundred thousand dollars. In making a comparison between open- and closed-cycle systems, a high hourly operating cost (open cycle) is balanced against a large capital investment and low hourly cost (closed cycle). When system operation exceeds several hundred hours per year, it has been demonstrated that closed-cycle operation is far less expensive.[22]

Proposed refrigeration system

A closed-cycle (recirculating) refrigeration system using helium is envisaged. The general plan is shown in

IV. Apparent mean thermal conductivity for selected superinsulators

Type	Insulator*	Reflector†	Thickness, cm	Shields/cm	Density, g/cm^3	Cold wall, °K	k, $\mu W \cdot cm^{-1} \cdot °K^{-1}$
1	A	2	3.3	55 (22)	12×10^{-3}	77	0.56
						20	0.39
2	B	1	3.8	50 (20)	11.2×10^{-3}	77	0.52
						20	0.42
3	B	1	2.5	50 (20)	11.2×10^{-3}	77	0.71
						20	0.60
6	A	1	3.6	37 (15)	11×10^{-3}	77	0.74
						20	0.52

Source: Kropschot *et al.*[18]
* Type A: fiber glass paper, 0.2 mm thick; type B: fiber glass paper, 0.12 mm thick.
† Type 1: aluminum foil, 0.013 mm thick; type 2: aluminum foil, 0.0058 mm thick.

Fig. 8. The main components are a full-range refrigerator, cryogen supplies, a pipeline carrying the superconductive cables and the cryogen, and terminals providing a transition from superconductive to ordinary cables. Since refrigerators and cryogenic supplies are readily available on the commercial market, the pipeline and terminations are the only components that require special design effort.

The helium refrigerator with liquid nitrogen precooling will be operated at a variable outlet temperature through the use of an internal bypass arrangement. After the pipeline and refrigerator are fully cooled, the refrigerator will produce subcooled liquid or saturated gas to be circulated through the pipeline. The refrigerator is conceived of as a trailer-mounted unit consisting of a helium compressor, heat exchangers, a storage vessel for liquid nitrogen (operated open cycle), a vacuum pump, and associated piping and controls. Cost of the 1000-watt refrigerator at 4.2°K is estimated at $550 000. Although it is a closed-cycle system, helium leakage has been observed in compressor packings. A helium gas makeup of about 100 standard cubic feet (2800 liters) per operating hour is a typical requirement for a kilowatt refrigerator.[22]

A cross-sectional view of the proposed pipeline is shown in Fig. 9. Starting with the central element, it consists of the cable bundle, the refrigerant conductor, the shield fluid conductor, and the thermal insulation.

For design purposes, the cable bundle has been assumed to consist of 150 miniature instrumentation cables formed into a compact unit by fitting over them a heat-shrinkable Mylar tube. Prior to the shrinking operation, each one-meter length of the covering tube and cable assembly is spirally rotated 180 degrees to provide sufficient excess cable length to accommodate contraction during cooldown (calculated at about one percent of length). The cable bundle is supported in the refrigerant conductor by stainless steel or Mylar clips designed to allow movement of the bundle in the refrigerant as it contracts during cooldown.

The refrigerant conductor consists of a Mylar polyester tube with shallow circumferential corrugations. The tube is installed in continuous lengths, and splices are made with polyester cement with the same thermal and physical characteristics as the tube itself. To insulate the helium in the inner pipe from the returning helium, a flexible polyurethane foam layer having an effective insulation thickness of 0.63 cm is extruded over the refrigerant conductor.

The returning helium gas in the shield fluid conductor will be at an average temperature of about 13.7°K. The operating pressure will be about 37 atmospheres. Thus the shield fluid conductor will perform as a low-temperature, pressure-containing element. To meet these requirements, it is made of a flexible corrugated stainless-steel tube with a wall thickness of 0.025 cm.

The primary thermal insulation for the pipeline is a high-vacuum layer containing superinsulation. The vacuum is established between the shield fluid conductor and a vacuum jacket constructed of stainless steel in a configuration similar to that of the shield fluid conductor. The outer surface of the vacuum chamber is covered with

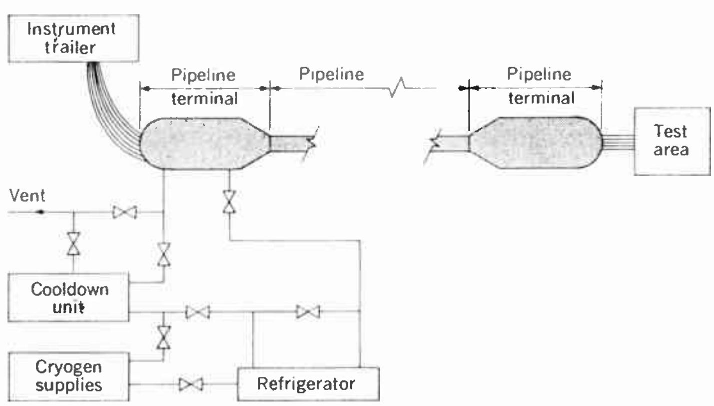
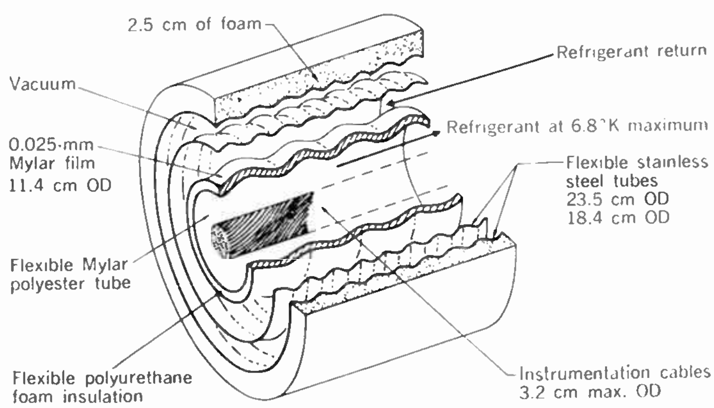


FIGURE 8. Plan of superconductive refrigeration system.

FIGURE 9. Section of proposed superconductive pipeline.



a 2.5-cm-thick layer of polyurethane foam plastic.

Since the entire pipeline structure is relatively flexible, each element must be supported at reasonable intervals and the entire pipeline must be supported continuously. Supports for the cable bundle, refrigerant conductor, and shield fluid conductor are stainless steel or Mylar circumferential bands with deep axial corrugations adjusted to span the radial distance completely between the inner and outer elements. The axial corrugations of the supports and the circumferential corrugations of the refrigerant and shield fluid conductors provide a very small contact area for heat transfer. The cable bundle is supported at intervals of about a meter, while the refrigerant conductor supports are spaced about 0.3 meter apart.

The vacuum jacket is supported by a continuous ribbon of polyethylene with dimensions of approximately 0.32 by 1.3 cm. The ribbon is laid spirally with a lead of about 0.3 meter and is installed during fabrication over the aluminized Mylar radiation shields.

Pipeline sections running horizontally either above or below ground level will be laid in a metal trough. The trough will be placed directly on the ground or, if the ground surface is irregular, slightly elevated on stanchions located at frequent intervals. The polyurethane foam layer on the pipeline's outer surface separates it from the trough and protects the line from ground transmitted vibration and heaving.

The pipeline terminations, shown in Fig. 10, are high-quality, special-purpose liquid-helium vessels carefully designed and constructed to assure the absolute integrity of the superconductive instrumentation system.

Fabrication, installation, and operation

The method of manufacture proposed for the pipeline is presently being used in the production of multiwall vacuum-jacketed piping for cryogenic applications. The nonmetallic elements—Mylar and polyurethane foam—are used quite extensively in cryogenic applications, and their physical and thermal properties have been extensively investigated and reported.[23,24]

The pipeline is capable of being factory assembled in lengths of about 30 to 300 meters. Each length is to be evacuated, cleaned, sealed, and equipped with end fittings for making field connections. The end fittings include evacuation ports, vacuum system instrumentation, and safety devices. For shipment to the Nevada Test Site the pipe will be placed on a cable spool about 3 meters in diameter.

Field assembly will consist of laying the metal trough sections, unrolling the pipeline sections directly into the trough, making the field joints and attaching the end terminals, and connecting the pipeline to the refrigerator.

Operating supplies will consist primarily of the cryogens required for both cooldown of the pipeline and the refrigerating equipment and for operation of the superconductive cable. Other supplies will include electric power and labor.

The pipeline should be operated in the superconductive state for one week following cooldown to check out the line and associated equipment. The checkout should be followed by a four-week period during which the pipeline will be kept in a standby condition at a temperature of approximately 19.2°K. The line should be cooled again to the superconductive temperature one week before the test and held at this temperature through the test period. Thus the operating period will be six weeks, plus the time required for the initial cooldown.

For initial cooldown, the pipeline is filled with warm helium gas at low pressure. The gas is recirculated until a uniform temperature of about 16.5°K is reached. Cooldown is completed by cooling the already cold helium gas flowing in the system to the desired final temperature. Intermediate temperatures are achieved by operating the refrigerator at partial load and bypassing a variable ratio of warm gas.

Operation of the system during the four-week standby period is similar to operation during cooldown. Since operating conditions are static during this period, only one attendant is required.

Cost analysis

An analysis of the cost of fabricating, installing, and operating a superconductive data transmission system at the Nevada Test Site is presented in Tables V and VI. This analysis is based on the following assumptions:

Pipeline length	1220 meters
Average heat leak	0.82 watt/meter
Refrigeration rate during operation	1000 watts at 4.2°K
Maximum temperature of superconductive cable	7.2°K
Cooldown rate	11°K per hour
Frequency of testing	one test per 12 weeks

Since the complete pipeline assembly incorporates several innovations, before large-scale production can be achieved some special tooling must be designed and produced and some assembly development must be carried out. The first pipeline sections produced are estimated to cost about $380 per meter. Subsequent pipeline costs will be greatly reduced, and after the first four 305-meter sections, additional 305-meter sections will cost about $90 per meter.

A large part of the pipeline and its support will be located at a considerable distance from the test area. It is anticipated that all of the noncapital equipment not seriously damaged in a test firing will be refurbished and made available for subsequent tests. It is assumed that one half of the pipeline and three fourths of the support system will sustain no damage and will be relocated and reused with a minimum of reworking. The cost involved in its reuse is estimated at 20 percent of the original cost. It is further assumed that an additional one fourth of the original pipeline can be reworked and returned to service at 50 percent of the original cost. The remaining pipeline and support and the far-end termination are assumed to be damaged beyond further use.

Capital equipment consists of a full-range liquid-helium refrigerator that combines cooldown and low-temperature refrigeration equipment into one capital equipment unit. The near-end termination is included with the capital equipment, since it is assumed to be designed with at least 150 electrical transition elements and electric terminals, and to be usable with any instrumentation cable configuration incorporated in a specific pipeline.

Capital equipment is evaluated on the basis of a ten-year useful life, which has been shown to be a reasonable life expectancy for equipment of this type in low-temperature service. Maintenance, insurance, and other costs directly related to capital equipment costs are estimated

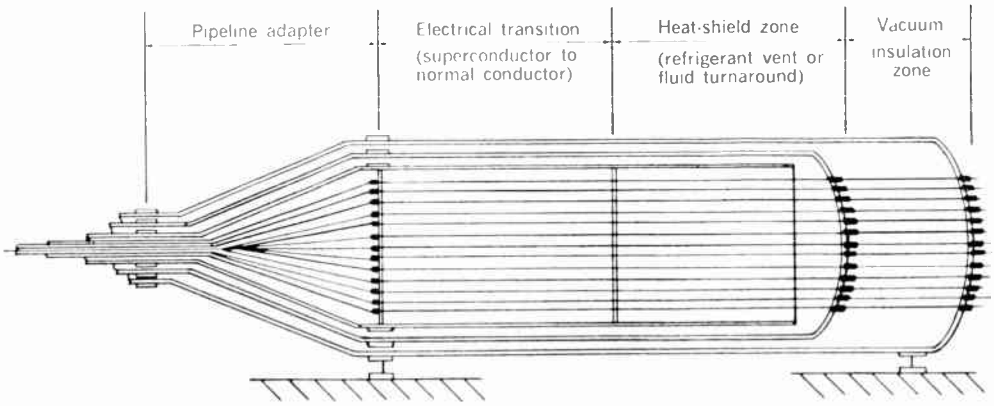


FIGURE 10. Proposed superconductive pipeline termination.

V. Equipment cost

Capital equipment	
Full-range refrigerator	$550 000
Near-end termination	35 000
Total capital equipment	$585 000
Noncapital equipment	
Cables*	$150 000
Pipeline†	140 000
Pipeline support system	10 000
Far-end termination	30 000
Total noncapital equipment	$330 000

* 150 1220-meter lengths of lead-coated miniature coaxial cable.
† 1220 meters of pipeline with field joints at 152-meter intervals; no allowance for salvage value.

VI. Cost of systems per test operation with salvage and reuse of pipeline and supports

Capital equipment	$ 13 500
Maintenance, insurance, etc.	2 700
Noncapital equipment	98 500
Operating supplies	62 150
Total cost per test	$176 850

at two percent of the original investment per year. A proportional part of these costs is charged to each test. The allowance of 12 weeks between tests permits 6 weeks for operation and 6 weeks for repair and relocation of the equipment.

Detailed engineering design of the refrigeration system proposed for use with the superconductive instrumentation system at Nevada Test Site was carried out for Sandia Corporation by Airco Cryogenics, Division of Air Reduction Company, Inc., Newark, N.J., under an AEC contract. The authors wish to express their appreciation especially to J. A. Proctor and S. H. Yang of Airco for their support of, and contributions to, the program.

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TVA—Nondomestic purchases by a government utility

Concerning the purchase abroad of heavy equipment by the government of the United States, feelings sometimes run high. In this article the director of purchasing for the Tennessee Valley Authority traces the pattern of that body's procurements during recent years

Raymond L. Forshay *Tennessee Valley Authority*

When a government agency purchases materials and equipment, it is required by law to accept bids from all qualified sources, except in cases of emergency. If the products are of equal quality, the agency must then buy from the lowest bidder, whether he be domestic or foreign. It is obvious that the utility industry in general, and the Tennessee Valley Authority in particular, rely heavily on European and Japanese manufacturers for a large percentage of their equipment needs. Price and delivery schedules are important factors; and the quality of products purchased abroad has generally been equal to or better than the comparable domestic product.

The Tennessee Valley Authority, as a public agency, must do its buying in a "goldfish bowl." In accordance with the TVA Act all purchases are conducted under competitive bidding procedures, except in cases of emergency or other specific exemptions. These provisions were written into the Act to assure full accountability in the use of public funds and, at the same time, to assure fairness to all qualified suppliers.

The TVA's total purchases over the past ten years have varied from a low of $112 million in 1958 to a high of $652 million in 1966. In this ten-year period purchases outside of the United States have averaged about 3 percent of the total procurement. Figure 1 shows the relationship of TVA's total purchases to its foreign purchases, and helps put them in proper perspective. A significant part of TVA's purchases is for coal; if we exclude coal then TVA's imported equipment purchases averaged about 7 percent of the total manufactured articles purchased over the ten-year period. During the past two fiscal years this ratio was 4 percent and 11 percent; and TVA saved approximately $40 million by purchasing from foreign suppliers as compared with the price quoted from the lowest bid of domestic suppliers on the equipment. However, this does not include any consideration of possible additional savings in domestic prices due to the presence of competition from abroad.

In making purchases from other countries, TVA follows the policy laid down in the Buy American Act and Executive Order 10582 issued by President Eisenhower in 1954. These documents provide that a domestic bid shall be deemed unreasonable and its acceptance deemed inconsistent with the public interest if the amount of the domestic bid exceeds the amount of the import bid by more than 6 percent. In accordance with a recommendation by the Council on Foreign Economic Policy, a 12 percent differential is used when the low domestic bidder is located in an area classified by the Secretary of Labor as one of labor surplus, or when the low domestic bidder is a small business firm. In addition, TVA includes in its evaluation of overseas purchases the added cost for any inspection or other expenses associated with the procurement. On all heavy electric equipment the bids are evaluated as to efficiency of operation or other factors specified in the TVA invitations. Also, of course, the foreign supplier must include import duty and added transportation costs for overseas shipment in his bid.

It is significant to note that the total U.S. balance of trade is favorable. Figures furnished by the U.S. Department of Commerce show that the country's trade surplus last year resulted in exports that were $4.1 billion greater than the imports. In the last six years the balance of trade has varied from $3.8 to $7.0 billion per year, but always

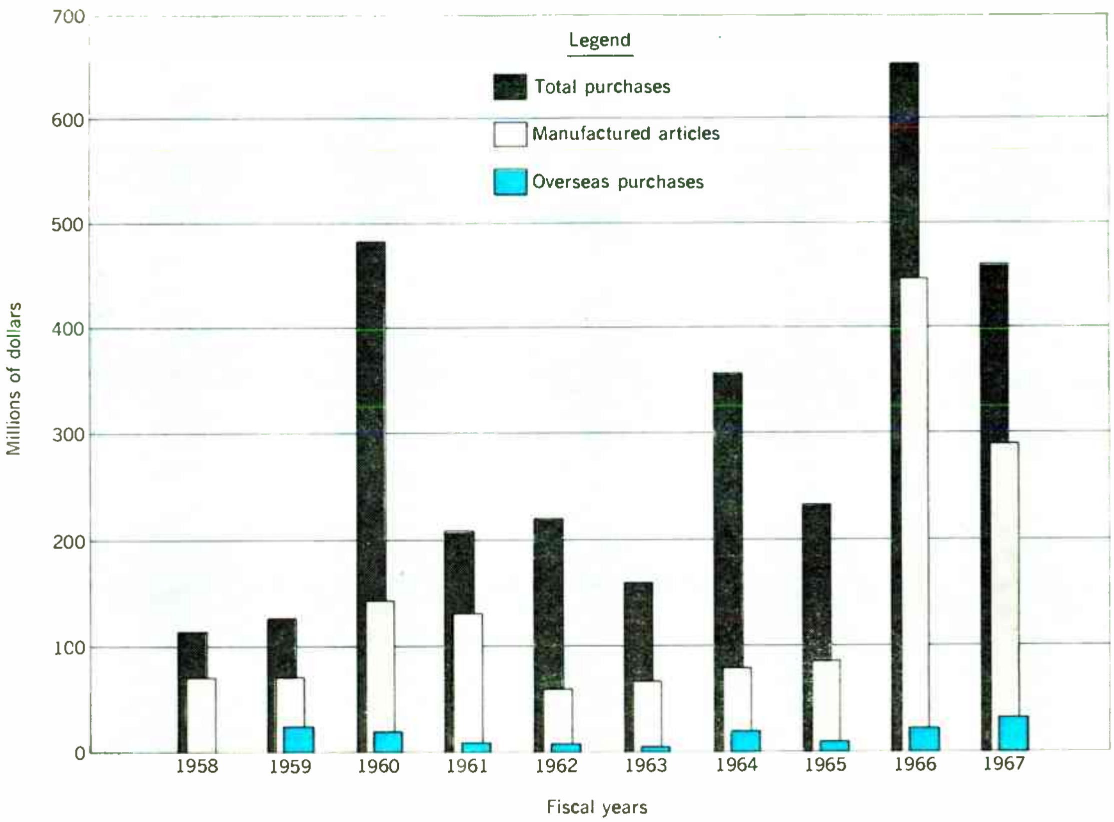


FIGURE 1. Tennessee Valley Authority purchases.

in the United States' favor. A stated policy of the U.S. Government is to stimulate international trade. This objective is universally accepted as being sound and desirable; only the method of reaching the objective is in dispute.

The importance of competition

The TVA carefully and continually analyzes its needs for materials and equipment in order to insure maximum economy, but it also takes into consideration the quality and reliability of equipment or materials being purchased, the availability of manufacturing facilities for repairs or maintenance, the lead time in manufacturing, and other matters pertinent to the specific requirement. Foreign manufacturers are not permitted to bid on TVA's requirements until TVA engineers have satisfied themselves that the company is indeed qualified and is able to meet TVA's specifications for the particular equipment. The Authority's experience with the quality of foreign products has been satisfactory.

In the late 1950s, when domestic prices were advancing faster than the increase in labor and materials costs, TVA began taking bids from manufacturers outside the United States on much of its heavy electric equipment. A study at that time showed that over a six-year period in the 1950s there were five increases in steam-turbine-generator prices totaling 53.7 percent. During the same period the composite steel and wage indexes used for estimating escalation rose less than 28 percent whereas the Wholesale Price Index for all commodities rose only 5.1 percent.

The utility industry has a good record for reducing the cost of electricity to its customers even though the price of labor and material has been steadily rising. Careful long-range planning, economies derived from interconnected systems and pooling arrangements, technological breakthroughs such as extra-high voltage and nuclear power, and economy of scale are all factors that have gone into this remarkable achievement. The manufacturers have been challenged and encouraged to forge ahead in these areas, and they have competed with each other to meet the challenge. The many technological developments occurring in the utility industry, and the public demands for ever-increasing amounts of electric power at lower rates, require continuing search for better equipment and materials and lower construction and operating costs.

Generally, domestic manufacturers have provided some degree of competition in technology, in service, in price, in delivery, and in equipment performance. Such competition among suppliers is important in assuring the development of even better equipment at reasonable cost for utilities' future needs. However, competition may fail to be an effective force when demand exceeds the production capacity of an industry or when the number of suppliers is limited. When there are relatively few sellers, and when one or more of them is large enough to make or break prices by independent action, all sellers usually follow this price leader. When a few large companies produce most of the output of an industry, they may avoid price competition without collusion; price changes may be almost simultaneous and uniform. In such instances it may be that the only remaining source for the injection of a competitive condition is from a nondomestic supplier.

The prudent purchase of heavy electric equipment, particularly in the utility industry where capital investment is so dominant, is a major factor in holding retail electric rates low. Interest in imported equipment results from the increasing domestic prices, long domestic lead times for delivery, pricing policies, the technological parity or superiority of some foreign manufacturers, and their demonstrated willingness and ability to perform in the development, manufacture, and delivery of such equipment. This interest has been kindled by some recent awards.

Milton Friedman, the former economics advisor to President Eisenhower and a frequent contributor to *Newsweek* magazine, recently wrote concerning imports of steel: "If steel can be purchased at a lower price from foreign than from domestic producers, then the U.S. steel industry has failed the market test. It is best for the nation that some of the men and capital resources devoted to producing steel be devoted to more useful pursuits—perhaps producing some of the products we shall then export in return for the steel we import." There may be a parallel situation in the area of heavy electric equipment. Certainly, in the long run, domestic manufacturers must improve their price competitiveness.

A look at the backlog of orders in the shops of the United States' suppliers of heavy electric equipment reveals that the facilities are pretty well loaded to capacity, which is no secret to utility buyers who are presently functioning in a sellers' market. Some of this is reflected in TVA's actual bid experiences.

The price of turbogenerators

The unusual price increases of domestic turbogenerators during the 1950s prompted TVA to explore foreign sources of supply. During the 15-month period between September 1957 and December 1958, the price of domestic turbogenerators rated at 500 000 kW—the size in which TVA was interested—increased approximately 9½ percent. The TVA invited bids from other countries for turbogenerators late in 1958. Prices quoted by the non-U.S. manufacturers at that time were approximately 30 percent below those quoted by domestic manufacturers, and an award was made to an overseas supplier. In 1959, TVA purchased another 500-MW turbogenerator from an extrinsic vendor at a price some 37 percent below the most favorable domestic offering. In March 1966, TVA opened bids for a coal-fired turbogenerator in the 1000-MW-plus class. The low overseas bid was about 32 percent under the low domestic bid. Bids opened in the fall of 1967 for large coal-fired turbogenerators showed the low extrinsic base bid to be 38 percent below the domestic. Furthermore, the import bids were firm and the domestic's were to be escalated.

Domestic manufacturers have, for the past several years, published price lists with variable multipliers. Rapid increases in domestic published prices for coal-fired turbogenerators of 800-, 1000-, and 1200-MW ratings have taken place in recent years. Between October 1965 and May 1967, the published price for the turbogenerators increased four times for a total of about 18 percent. Between October 1964 and May 1967, the domestic published prices for nuclear turbogenerators of 800-, 1000-, and 1200-MW ratings increased five times for a total of approximately 29 percent.

Wholesale Price Indexes for Selected Materials used in the manufacture of such items as power transformers, switchgear and switchboard apparatus, and steam-turbine-driven generators appear to show varying patterns between 1958 and 1962. Beginning in 1962 and continuing through 1967, there has been a continued increase in these indexes. Materials used in the manufacture of power transformers, switchgear, and switchboard apparatus appear to be increasing about 5 percent per year. Materials in the steam-turbine-driven generator category appear to be increasing about one percent per year. Average hourly earnings for workers in the electric equipment and supplies industry, as published by the Bureau of Labor Statistics, have increased about 30 percent over the past ten years—an average increase of some 3 percent per year. The Wholesale Price Index for Industrial Commodities has increased about 6 percent since 1963—an average of some 1½ percent per year.

Domestic prices for heavy electric equipment appear to be rising considerably faster than the indexes of labor and material during the same period. Such price increases invite competition from other areas of the world. The recently announced limitation on escalation of domestic turbogenerators was obviously the result of active overseas competition.

Delivery and lead times have recently become somewhat of a problem—probably one that the utilities themselves have aggravated with the surge of orders during the past couple of years. Except for insulators, deliveries offered by both domestic and extrinsic suppliers have generally been in accordance with the delivery dates specified in TVA invitations; however, the Authority, as with all utilities, has been alert to the stretch in lead time and, consequently, has been planning further ahead. If all orders placed by the utilities during the past few years had gone to domestic suppliers, the domestic delivery situation could even be worse. Generally speaking,

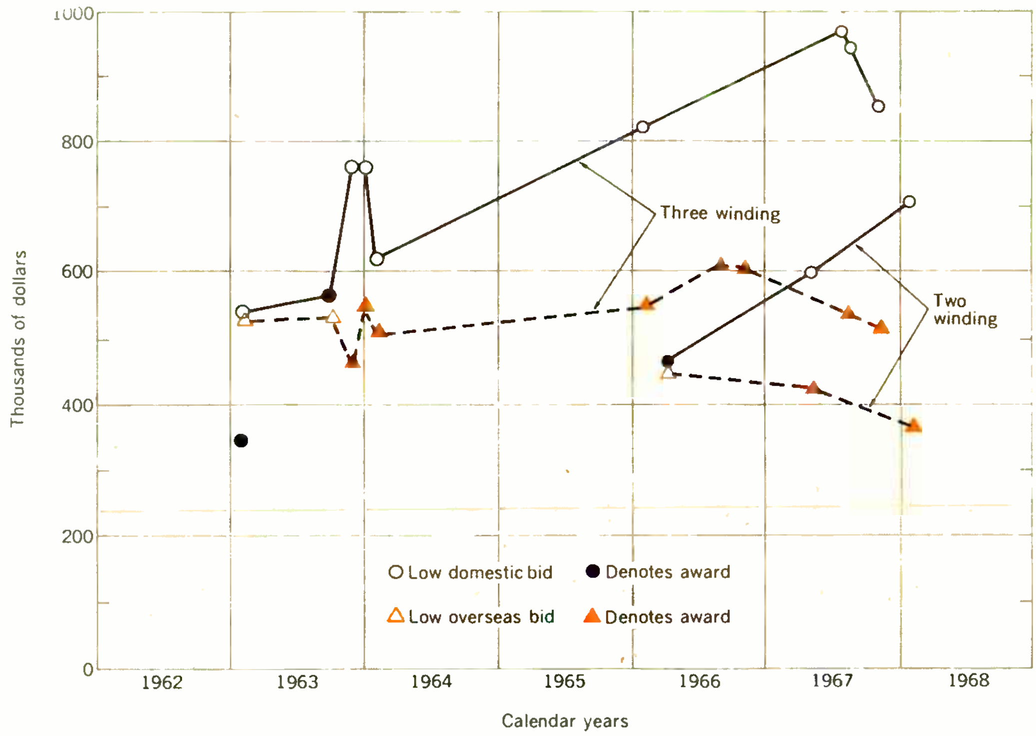


FIGURE 2. Single-phase, two- and three-winding 500-kV power transformers, 400-MVA rating; low domestic and low overseas bid prices.

it seems that suppliers outside the U.S. are now able to deliver earlier than domestic suppliers.

Power transformers

The Tennessee Valley Authority's first 500-kV transmission line was placed in service barely three years ago but there are now in service or under construction more than 1600 km of such line, plus ten 500-kV switchyards. Because TVA's 500-kV system is required to carry very large loads, equipment specifications are quite stringent. Only technologically sophisticated manufacturers are qualified and equipped to design, manufacture, and test our EHV transformers. At present, TVA is receiving bids from only two domestic suppliers; four or more overseas suppliers usually bid. The first TVA contract for 500-kV power transformers was made in 1963 with a domestic manufacturer. From Fig. 2, which shows the low domestic and low extrinsic bids for two- and three-winding 500-kV power transformers in the 400-MVA class, it is evident that domestic prices have increased rapidly whereas import prices have remained relatively stable or have decreased. Prices from both sources started out at about the same level for the first bids received. However, the domestic prices for three-winding transformers have risen approximately 56 percent during a 4½-year period, an average increase of about 12 percent per year; during this same period, foreign prices have declined about 2 percent. It is also significant to note the sharp drop in domestic bid prices late in 1967—a decrease of some 13 percent.

Bid prices for two-winding transformers present a more unusual picture. During the last two years, domestic prices have increased a total of approximately 53 percent. During the same two-year period, foreign prices have declined by 18 percent. Only one domestic bid was received on TVA's most recent invitation shown. This unusual pattern of price changes is the primary reason that 40 of the 52 500-kV power transformers purchased by TVA during the last five years have been purchased from manufacturers outside the United States, resulting in a savings of approximately $9 500 000.

In the early 1960s TVA's purchases of 161-kV transformers were mostly from domestic manufacturers. However, domestic competition for TVA's requirements in this class transformer is growing less effective. There are six domestic and nine nondomestic companies on TVA's bidders' list for 161-kV transformers.

Domestic prices for single-phase 161-kV power transformers have increased about 65 percent from the low in 1963. Labor and materials indexes related to the industry have shown increases of 13 percent and 20 percent respectively. During this same period foreign prices increased only 11 percent—less than 3 percent per year, with a sharp drop in 1967.

Figure 3 shows domestic and nondomestic bids for three-phase 161-kV transformers. The TVA has not taken bids on this particular size of transformer since the middle of 1967. At that time, the domestic bids had been increasing sharply—the increase from June 1965 was 73 percent; foreign prices had an upturn at the middle of 1965, but had three successive decreases in the first half of 1967. The net increase in the foreign price for the two-year period was about 20 percent. This history of 161-kV transformer bids illustrates why most of TVA's transformer requirements for 1966 and 1967 were furnished by manufacturers outside the United States—some 66 out of a total of 89.

Domestic suppliers have dominated TVA's market for 69-kV transformers; foreign suppliers have not met with

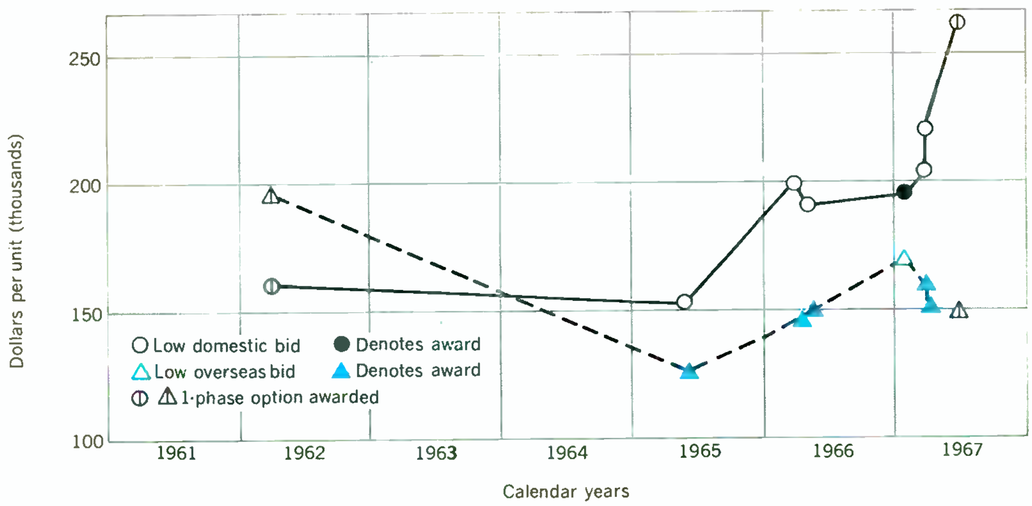
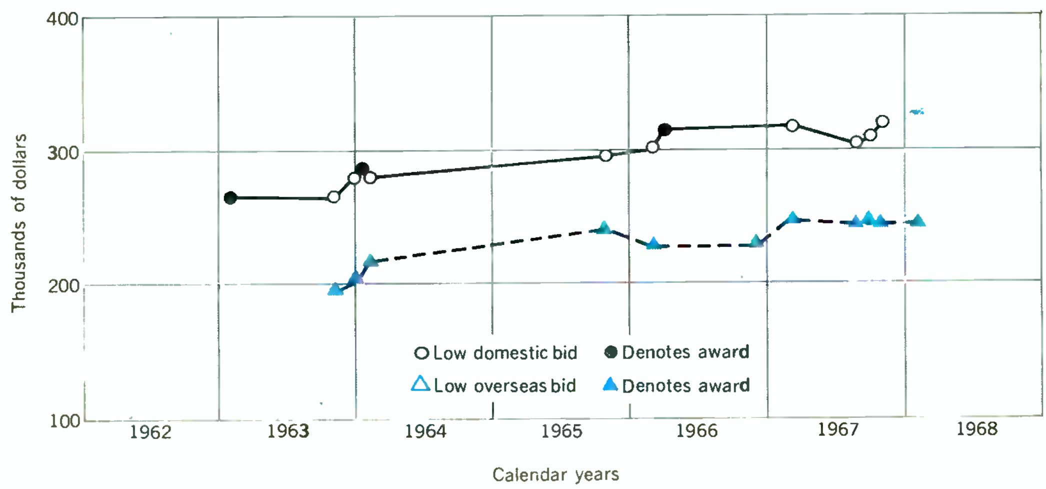


FIGURE 3. Three-phase, three-winding, 45-MVA rated power transformer bids.

FIGURE 4. Low domestic and low extrinsic bid prices for 500-kV power circuit breakers.



any appreciable competitive success. The TVA has eight domestic bidders out of a total of 12 for this class of transformer. Figure 3 shows the relationship of extrinsic and domestic prices for 69-kV power transformers during the 1962–1967 period. Although prices have increased substantially in this class of transformer, the domestic industry appears much more aggressive and provides very strong competition with the foreign suppliers. Eighty-six percent of TVA's requirements of 69-kV power transformers were purchased from domestic manufacturers from 1962 to 1967, with a minor 14 percent being awarded to other suppliers.

Power circuit breakers

Tennessee Valley Authority experience in the purchase of power circuit breakers is quite similar to its experience with respect to power transformers. In the very large circuit breakers that are needed for the 500-kV transmission system, the number of qualified suppliers who can meet TVA specification requirements is very limited. In the United States there are only three capable bidders. One of these is bidding under license from an overseas manufacturer, and another has had some problems in meeting TVA specifications. It thus boils down to the fact that there is only one domestic supplier who now bids a domestic design for the circuit breakers. On the other hand, there are only two or three nondomestic suppliers currently capable of furnishing this equipment to TVA's specifications. Thus, the competitive area is quite limited, and the need for using all sources of supply is apparent.

The low domestic- and the low foreign-bid prices for 500-kV power circuit breakers are shown in Fig. 4. Note that the price trends parallel each other. Domestic prices have increased only 21 percent since 1962—about 4 percent per year; prices abroad continue to run about 30 percent below domestic. Price increases for this commodity appear to follow closely the trend in labor and material price increases. Of 47 500-kV breakers purchased by TVA to date, 36 have been imported.

With regard to 161-kV power circuit breakers, there is a greater capability in the United States, and thus a larger number of suppliers. The TVA has five domestic suppliers on its mailing list for this class of circuit breakers, and no foreign supplier. Since 1962, prices have increased about 38 percent. This rate of increase is nearly

I. Insulator delivery and price, domestic and foreign, December 1965 to December 1967

Requested Delivery, days	Domestic Price	Foreign Price	Domestic Delivery, days	Foreign Delivery, days
210	3.90	2.52	700	210
130	4.10	3.47	1095	90
203	7.00	3.63	145	190
25	1.79	1.52	210	275
14	1.35	1.05	400	360
238	1.90	1.35	750	245
51	2.51	1.70	245	220
126	9.65	7.50	500	216
48	20.40	17.55	350	275
75	37.50	29.40	900	75
55	35.70	24.00	1095	45
105	31.57	20.36	200–1700	150
164	32.55	19.78	164–450	150
123	72.48	46.50	224	420
337	75.50	37.90	304–670	380–410
618	520.00	495.00	618	618
618	440.00	255.00	618	618
436	12.30	10.45	1000	375
162	21.84	9.79	900	250
195	43.79	36.53	1050	395
167	16.35	13.65	2190	170–230

double the rate of increase for 500-kV circuit breakers. On the other hand, there has been virtually no outside competition in this market.

The Tennessee Valley Authority is now facing a difficult problem because none of its suppliers of 161-kV circuit breakers is showing interest in developing a high-capacity breaker with a greater interrupting rating. Such a breaker is needed now, and soon will be essential to TVA's future system. The largest manufacturers who previously supplied the breakers have discontinued making equipment of this class, even though there was no outside competition.

In the still lower power-circuit-breaker ratings, at 14.4 kV, there is an adequate number of domestic suppliers to provide active competition, and TVA has no overseas bidders for this class of breaker. Since early 1961 prices have increased some 43 percent, an average annual increase of 7 percent. This rate of increase has been higher than the rate of increase for labor and materials. A comparison of the bid history on the three classes of circuit breakers indicates that where foreign competition was present domestic prices increased at a slower rate than where competition was absent.

Suspension insulators

For the past several years a major share of TVA's porcelain requirements has come from nondomestic sources. The principal reasons for this are delivery and price, and, in some cases, special design requirements. The Tennessee Valley Authority does not wish to detract from the accomplishments of the U.S. procelain industry; the many developments that it has made have served to improve the reliability of power equipment and transmission systems. The Authority will gladly use domestic products if they meet specifications, if delivery can meet construction schedules, and if the price is reasonably competitive.

Table I is a tabulation of TVA's experience with insulator delivery and prices from domestic and overseas suppliers for 1966 and 1967. Deliveries quoted by the domestic suppliers range generally from about 250 days to something over 1000 days; in the last instance quoted, it was over 2000 days. Comparable deliveries from nondomestic suppliers are considerably less, with a maximim delivery of 618 days, which, incidently, was as TVA requested. It has been our understanding that the productive capacity in this industry has been very strained, at least insofar as supply to TVA is concerned. And the suppliers have not been in a position to quote deliveries that would meet TVA's construction schedules.

It is quite clear that the utilities industry in general, and also many of the manufacturers of electric equipment, have relied heavily on the Japanese and European sources for a sizeable portion of their insulator and porcelain needs. Apparently, both price and delivery have been important factors, and quality has been equal to or better than the comparable domestic products.

In bids that TVA has requested from both domestic and extrinsic suppliers, domestic manufacturers have offered to meet TVA's delivery date approximately 20 percent of the time. However, in each case, except one, the domestic price was 50 percent or more higher than foreign bids. Domestic lead times have reached prohibitive levels in some instances, and overseas lead times appear to be lengthening. The demand for nondomestic insulators appears to be slowly catching up with the supply, so that some increase in price may be expected.

Conclusion

The facts show that the U.S. electric utilities are providing plenty of business for equipment manufacturers, probably more than they can handle. The electric industry is growing steadily, and there is no sign that its rate of growth is tapering off. In very few manufacturing lines can the producer anticipate the needs of the future with as much certainty as can the electric utility suppliers. The domestic industry has many things going for it that other industries don't have; in those instances where other suppliers seem to have an advantage, domestic suppliers should be fully capable of meeting competition.

The facts indeed show that foreign competition has strengthened domestic industry. The industry has found that it could compete successfully with nondomestic manufacturers and stay within the bounds of the antitrust laws. The result has been lower costs for both the utilities and for their customers throughout the United States.

Extrinsic supply is available to augment domestic supply if the latter, in any given area, becomes inadequate, if domestic lead times become excessive, if domestic technology fails to keep pace with requirements, or if domestic prices continue to increase disproportionately. The presence of foreign competition provides the domestic manufacturers with an added incentive to overcome these obstacles—and we are confident that the presence of competition is a healthy ingredient in the U.S. business community.

Essentially full text of a paper, "Price Trends and Foreign Supply," presented at the American Power Conference, Chicago, Ill., Apr. 23–25, 1968. This paper will also appear in the *Proceedings* of the conference.

Scanning the issues

Liquid-Crystal Flat Screens. The discovery of a new reflective effect in certain classes of "nematic" liquid crystals has opened the possibility of the development of cheap flat display screens that might be used in conjunction with solid-state and integrated circuitry. Although such displays are far from the applications stage, experimental liquid-crystal devices have already been demonstrated. They include a tiny "electronic window shade" consisting of a sheet of glass that changes from transparent to opaque when voltage is applied; an all-electronic clock with no moving parts, on which time is told by liquid-crystal digital display; a high-resolution nonmoving 7.5- by 10-cm picture display on which a television test pattern appears when a button is pressed; changing numerical indicators designed as substitutes for Nixie tubes. A characteristic of these flat-screen liquid crystal displays is that the picture increases in visibility and contrast as the surrounding light increases, so that the picture is best in direct sunlight. Potentially, these sandwich construction displays, which consist of liquid crystals trapped between two sheets of thin glass coated with electrode material, could be cheap, possess extremely small power requirements, and might even lend themselves to line-at-a-time matrix-addressed, real-time displays. An in-depth technical description of the discovery appears in the July issue of the PROCEEDINGS OF THE IEEE.

The term "liquid crystals," the authors of the paper say, is applied to substances whose rheological behavior is similar to that of fluids but whose optical behavior is similar to the crystalline state over a given temperature range. Nor are liquid crystals rare. Roughly one out of every 200 organic compounds exhibits mesomorphic behavior, although the occurrence in inorganic substances is extremely uncommon. The feature common to molecules exhibiting liquid crystallinity is a planar, rod-like structure. In fact, the term "nematic" is from the Greek meaning "thread," and describes the thread-like lines that can be seen in liquid crystals under a microscope. Nematic materials can be aligned by both electric and magnetic fields.

The new reflective effect (it is really due to the *scattering* of light) is related to the disruptive effects of ions in transit through the aligned nematic medium, which results in the formation of localized scattering centers. The ions can be produced by field assisted dissociation of neutral molecules and/or Schottky emission processes. Rise times of 1 to 5 ms and decay times of less than 30 ms, together with dc operating voltages in the 10- to 100-volt range, make dynamic scattering seem attractive for such applications as alphanumeric indicators and other applications already mentioned. Reflective contrast ratios of better than 15 to 1 with efficiencies of 45 percent of standard white have been demonstrated.

The possibility that thin-screen liquid crystal displays might compete practically with vacuum-tube displays such as the oscilloscope makes their discovery significant for both research and commercial interests. (G. H. Heilmeier *et al.*, "Dynamic Scattering: A New Electro-optic Effect in Certain Classes of Nematic Liquid Crystals," *Proc. of the IEEE*, July 1968.)

Status of Biomedical Engineering. In recent years, the interaction between the engineering sciences and biology and medicine has been quickening in many university, government, and industrial laboratories throughout the United States. Indeed, there are signs that biomedical engineering is reaching a takeoff stage for an even more rapid and vigorous growth.

Although no single review could hope to document the interactions of the many scientific fields involved in biomedical problems or convey in depth the status of current research and development, a committee report on the "Status of Research in Biomedical Engineering" appearing in the current IEEE TRANSACTIONS ON BIO-MEDICAL ENGINEERING offers a comprehensive overview that is sure to be useful to anyone who has the slightest connection to or interest in the biomedical field. The report, prepared by a group of consultants (headed by Lawrence Stark) at the behest of the Biomedical Engineering Training Committee of the National Institute of General Medical Sciences, is cohesive, quite readable, and constitutes, in fact, a small education on the whole biomedical field. Although the report is not able to go into single research activities, its more than 200 references will lead the willing reader to much of the prominent biomedical research.

The report is divided into eight major sections, the first four being devoted to the classical engineering or *building* aspects of bioengineering, the next three being concerned with the scientific, intellectual, and academic influence of bioengineering in the life sciences, and the last section being concerned with future goals of bioengineering in terms of directions, problems, and probable ways in which needs may be met. A few selected points from these sections should serve to indicate the scope and level of this report.

Section I deals with biomedical instrumentation, and includes both transducers for measurement and control, complex transducers, and systems of instrumentation. The transducers discussed include both passive and active kinds that measure such biological quantities as blood pressure, temperature, velocity, and constituency, heart capacity, frequency, sounds and electrical activity, and so on. The transducers are mechanical, optical, acoustical, chemical, resistive, inductive, capacitive, photoelectric, piezoelectric, thermoelectric, etc. Exciting advances being made with active transducers include the use of ultrasound, lasers, fiber optics, microminiaturization and implantation, telemetry, cryogenics, prosthetics, and the complex instrumentation systems involved in extracorporeal maintenance of circulatory or renal function. In their discussion of such advances, the authors note that the most significant electronic development of this decade has been integrated microminiature circuits that can be directly applied in implantable instruments for metering and control.

They also note that although trends in biomedical instrumentation have been toward better display and more quantitative measurement, it is not always easy to gain acceptance for newer, more expensive, and more complicated equipment, and they cite the continued universal use of the stethoscope as a proof that, despite considerable bioengineering effort, a more successful way of handling heart sounds has not been found.

Section II, which deals with prosthetics or artificial organs, duly notes the materials problems as being of prime importance, followed closely by problems of control, power supplies, maintenance, and repair. Section III deals with man-machine systems and includes the interaction of man with machines for working and the interaction of man with the environment so as to control material in the environment rather than pollute it. Section IV on computers is more information-systems-oriented than hardware-oriented, and stresses the impact of digital computers both in the *design* aspects of bioinstrumentation and in the *analysis* of biosystems. It covers numerical uses, simulation, signal processing, complex instrumentation systems, hospital information systems, man-computer interaction, and so on. Section V deals with classical engineering physics applied to such areas as cardiovascular hemodynamics and cardiac electrical field studies. Section VI deals with cybernetics or systems science, and includes control, information theory, the analysis of physiological, biophysical, and biochemical systems with engineering conceptual methods, and bionics, which has to do with the use of biological principles in widening concepts of engineering design.

Even beyond the particular scientific and engineering developments in its implications and influence is the question of education. Section VII deals with the interaction of bioengineering and other academic curricula.

In this section, the committee stresses that at the present time the medical world is in a crisis. Developments in mathematics, physics, and engineering sciences, it observes, have outstripped the understanding of general practitioners, medical students, and even members of academic medical faculties. For this reason, such important institutions as the National Institutes of Health in Washington are turning increasing attention to the "continuing scientific development" of the medical scientist. This means re-education of senior medical people and faculty personnel in such areas as bioengineering, biomathematics, and physics. It has also become apparent, the committee states, that it is necessary to restructure the general process of medical education. For example, just as in 1900 it was important to introduce chemical science into medicine, in the 1970s it will be equally important to incorporate engineering system science into the medical curriculum.

Two directions are foreseen for bioengineering in the curriculum. One is toward more graduate-level mathematics, engineering, and physics for medical students. The other is toward practical interaction with the technological world of instrumentation, computers, and systems science that will be the dominant influence in the delivery of medical and health services to patients in hospitals and in the community.

As for the last major section of the report on goals, suffice to say that the major problems are outlined, and nine goals are identified as possible foci for planning efforts. Possible mechanisms are offered for solving problems at the level of the individual scientist, at the level of cooperative programs, and at the level of "centers of excellence." The general philosophy advocated, the committee concludes, should not be either a preponderance of planning or an argument for anarchy, but rather, as Jerome Wiesner of M.I.T. has said, a "planning for anarchy"– that is, enough planning of resources so that independent scientists and individual universities can strengthen their efforts, generate further resources, and interact in the rather free and probabilistic way that, it is said, characterizes the scientific community.

The committee report, which spans only 20 pages, thus covers a vast ground. A measure of its success is that it does so without seeming too abstract and empty, and leaves the reader with substantial things to think about. ("Status of Research in Biomedical Engineering," *IEEE Trans. on Bio-Medical Engineering*, July 1968.)

Advances in Applied Magnetics. A documentation of the major points of technical development in the application of magnetics during the past two decades is the substance of a special issue of the IEEE Transactions on Magnetics. A key function of review papers, guest editors W. Lee Shevel, Jr., and Robert F. Elfant stress, is to separate the trivia from the really significant progress. There is no substitute for both perspective and imagination on the part of the authors, the editors claim, and in this special issue this responsibility to readers is satisfied without exception.

Developments in permanent magnet materials are described by J. J. Becker *et al.*, superconducting magnets by W. B. Sampson, magnetostrictive materials by Y. Kikuchi, microwave ferrite materials and devices by R. F. Soohoo, ferrite memory systems by L. A. Russell *et al.*, magnetic film memory systems by A. V. Pohm and R. J. Zingg, and magneto-optics by M. J. Freiser.

The increasingly widespread applications of magnetic materials should in itself recommend this special issue to many readers. (*IEEE Trans. on Magnetics*, June 1968.)

Dry Run . . . . or . . . .
How to Give a Slide Talk

Bill. We've asked you to attend this dry run because Bob here has worked out what we think is a particularly important presentation. He's going to give an invited paper describing the development of our Mark IV Nuclear Reactor to a session at the IZZZ International Convention the day after tomorrow. Bob, you can just take over from here.

Bob (starts writing an equation on the blackboard, copying it from a paper in his hand; it is endless).

Tom (after the blackboard is about half filled). Hey, what's that all about?

Bill. Excuse me, Tom, but we agreed not to interrupt the speaker until he gets through with his dry run.

Tom. All right, but he can't start out that way. If he doesn't begin with an opening statement of some kind, he's going to lose half his audience.

* * *

Those immortal words are from a playlet by James M. Lufkin about how to present a slide talk at your favorite convention. The playlet was presented at the March Convention and now appears in printed form in the current issue of the IEEE Transactions on You Know What. It is quite funny even in the printed form, and seems slated to go into the yearly repertory of the IEEE, especially since our society is a young and growing organization, with new young engineers coming along blessed with those eternal foibles of how not to give slide talks. In his little drama (a cousin of Molière's), author Lufkin gives everybody his comeuppance. Poor Bob sweats and agonizes his way through the rehearsal before his boss presenting *in plain English*, and in 20 minutes, the subject he has worked on for ten years. Poor Bill, the project engineer, is a straight man epitomizing the dreadful way these slide talks usually go. Poor Stan, the company editor, seems merely the alter ego of frightful Tom, the chief engineer, who is the real guy of this drama. He cuts through the grease like a demonic Mr. Clean, and you can see why he is the chief. After he operates, everybody gives good slide talks. One can almost imagine that Mr. Lufkin modeled Chief Tom after a real person, perhaps even his own chief—which is maybe why Lufkin does such a nice clean job on his dry run tutorial. It's worth reading. (J. M. Lufkin, "The Slide Talk: A Tutorial Drama in One Act," *IEEE Trans. on Engineering Writing and Speech*, July 1968.)

Advance abstracts

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

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

Proceedings of the IEEE

Vol. 56, no. 9, September 1968
M—\$2.00; L—\$3.00; NM—\$4.00

(Special Issue on MHD Power Generation)

Optimization Studies on Open-Cycle MHD Generators, *C. Carter, J. B. Heywood*—An optimization theory is developed that predicts the variation of thermodynamic properties, duct shape, and electrical loading along an MHD generator for minimum duct length, duct surface area, or duct volume. The model is based on the one-dimensional flow equations including heat transfer and friction, and the analysis is developed for a fluid with arbitrary dependence of density, enthalpy, electrical conductivity, and mobility on temperature and pressure. Four types of electrical loading of the generator are considered: the segmented-electrode Faraday generators; and the cross-connected generator, first with constant cross-connection angle and multiple-load connections; then with a single load; and finally with constant cross-connection angle and with single load. This theory is then applied to the design of an open-cycle MHD generator for a 2000-MW power plant. Numerical results for these four different types of generator are calculated with a computer program and compared, with particular emphasis on the loading parameter variation. It is concluded that the additional constraints of constant cross-connection angle and single load do not significantly affect the overall generator performance, although they do modify the parameter variation along the duct.

MHD Induction Generator, *S. J. Dudzinsky, T. C. Wang*—The general theory of MHD induction generators is reviewed in some detail. Several different approaches to the analysis of constant-velocity generators are summarized and compared, and a new mathematical model for a variable-velocity generator is presented, including digital computer solutions for the theoretical performance. The velocity distribution and boundary layer losses are considered separately, and the problem of end effect is discussed qualitatively. Recent experimental results for both separately excited and self-excited MHD induction generators are summarized, and the future of MHD induction generators is discussed briefly.

Disk Generator, *J. F. Louis*—The use of the disk generator as a practical device for power generation is discussed and compared with a linear device in terms of maximum allowable electric fields, magnetic field utilization, and surface-to-volume ratio. The swirl induced by the azimuthal force acting on the radial current is found to be of prime importance for the generator's performance. For certain values of the inlet swirl opposing the azimuthal Lorentz force, the output current becomes a conductive current as in a Faraday generator, and this results in increased efficiency for given Hall coefficients and loading. Examples and design concepts are discussed.

An Analysis of the Operation and Stability of the Constant-Velocity MHD Hall Generator, *J. K. Carey, W. F. Hughes*—The constant-velocity Hall-type MHD generator with segmented transverse electrode is analyzed numerically to determine the steady-state operating characteristics and the stability with respect to axially propagating magnetoacoustic waves under a constant-current constraint. The electrical conductivity and Hall parameter are represented as functions of temperature and pressure. The variations of steady-state parameters are displayed graphically and terminal characteristics are presented. Phase velocity and amplitude data for the magnetoacoustic waves are presented in terms of steady-state parameters under a short wavelength approximation. Three wave modes are predicted, two which damp and one which grows. For initially subsonic conditions, the two damped waves propagate downstream and the amplified one propagates upstream, which may cause choking. For initially supersonic flow the three waves all travel downstream.

Variable-Velocity MHD Induction Generator with Rotating-Machine Internal Electrical Efficiency, *D. C. Elliott*—A traveling-wave MHD induction generator with varying fluid velocity between inlet and exit can have the same internal electrical efficiency as a rotating induction generator. The fraction of electric retarding work converted to electric output at each station in the flow channel is $(1+s)^{-1}$, where s is the local slip $(U-U_s)/U_s$ between the velocity of the fluid U and the velocity of the zero crossing of the magnetic field wave U_s. To produce the rotating-machine efficiency, the product of magnetic field amplitude, wave velocity, and flow channel width is held constant from inlet to exit. The local slip can be freely chosen for maximum electric output from the fluid in the presence of friction, and the inlet magnetic field can be selected for maximum output after winding and end losses. An efficiency of 0.63 is found possible with a 325-kW lithium generator.

Transport Properties of MHD-Generator Plasmas, *C. H. Kruger, M. Mitchner, U. Daybelge*—The kinetic theory of partially ionized plasmas is applied to the calculation of transport properties for plasma conditions representative of MHD generators. Emphasis is placed on the accuracy of approximate formulas in comparison with the exact values. The exact values are obtained by means of spherical-harmonic expansions of the electron and heavy-particle Boltzmann equations, with the use of simplifications associated with the small electron mass. Consideration is given to both electron and heavy-particle properties in the presence of a magnetic field, including electrical and thermal conductivity, thermal diffusion, and viscosity coefficients, and allowing for differences between the electron and heavy-particle temperatures. In all cases it is found that accurate results can be obtained by simpler means than the classical Chapman–Enskog calculation, but that various approximate formulas differ significantly in their accuracy. Several new formulas are proposed. The influence on these results of differing cross sections is discussed, as are the effects of nonelastic collisions in the electron energy equation and the difference between quasiscalar properties in a magnetic field and those that apply in the absence of or in the direction parallel to a magnetic field. Corrections to the calculations when the plasma parameter ln Λ is not large are considered.

Some Diagnostics Techniques Useful for MHD-Generator Plasmas, *R. Wienecke*—The plasma in an MHD generator is mainly defined by its electron density n_e, its electrical conductivity σ, the temperatures of the gas and the electrons T_o and T_e, its velocity v, and the value of the Hall coefficient $\omega\tau$. Various diagnostic methods that are described were developed in recent years to determine and clarify the behavior of such generators.

Observations of Large Nonequilibrium Conductivity in a Closed-Cycle MPD Channel with Applied Electric and Magnetic Fields, *M. G. Haines, I. R. McNab*—Experiments have been performed in the International Research and Development (IRD) Mk II helium-cesium MPD facility with simultaneously applied electric and magnetic fields. By increasing the total current density in the plasma from 2 mA/cm² to 440 mA/cm² the plasma impedance decreased by a factor of 100 owing to a nonequilibrium increase of the electron temperature and number density. Nonideal behavior in the form of a much reduced Hall potential was always present and is attributed mainly to nonuniformities in the plasma conductivity, probably as a result of inadequate mixing of the seed material with the buffer gas. Other mechanisms known to contribute to the lowering of the generator performance include wall and plasma-to-ground leakage and finite segmentation. Further evidence for the large nonequilibrium decrease of plasma resistance with current was the amplification and harmonic generation of small voltage fluctuations.

An Absolute Immersion-Type Electrical Plasma Conductivity Probe, *E. J. Stubbe*—The feasibility of measuring the spatial distribution of the electrical conductivity in plasmas by

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to find what happens when "Old 97" hits that White Oak Mountain.

Kenneth Mortimer
Valparaiso University
Valparaiso, Ind.

I want to thank Prof. Mortimer for his kind comments on Part I of my railroad electrification article. I suppose my misinformation that there was still limited electric service on the Great Northern's Cascade Tunnel resulted from relying upon another railroad report. I should have consulted Great Northern. Sorry about that. And I probably should have mentioned the Illinois Central electrification. I always thought of the Chicago South Shore and South Bend, however, as more of an interurban high-speed trolley system, but perhaps, as Prof. Mortimer indicates, it should be considered as a full-fledged suburban line.

As to the fate of "Old 97," I regret to say that I cannot remember any more of the verses.

Gordon D. Friedlander

Moore comments

Just completed the somewhat depressing description of the state of electrical engineering education by Prof. A. D. Moore (IEEE SPECTRUM, July 1968, pp. 79–82). I couldn't agree more with the author's amazement at the poor performance of some E.E. seniors on the fundamentals of electromagnetics. In the haste to present state-of-the-art subject matter (lasers and masers, holography, solid-state physics, etc.), contemporary E.E. curricula tend to present a superficial treatment of the bases of these topics. Prerequisites of understanding are assumed, too often, perhaps, mistakenly.

With a sigh, I think back to a conversation between some of us graduate students prior to the Ph.D. oral exams. We decried the type of very basic questions the professors always asked on these exams and noted that, for our six to eight years previous education, it was never really necessary to examine elementary principles and postulates in order to be successful in course work. It seemed as though the questions about the very bases of electrical engineering were saved for just such special occasions!

With regard to the rest of the article's content, I am in disagreement with the author. He states, "In short, our texts are becoming completely mathematical and theoretical. How much engineering do they leave room for?" This implies that mathematics theory and engineering are separate. The use of "invariant principles" and "generalized machines" is lamented.

Consider a type of generalized machine, the pendulum. Although hardly "practical," does not a thorough examination of the pendulum, experimentally and mathematically, convey the basic principles of all oscillatory phenomena? Faced with the proliferation of devices with which he might deal with in his job, the engineer must be familiar with the unifying or invariant principles. How much easier life becomes when he realizes that such diverse topics as ac circuits, holography, and antenna radiation patterns can be described in the same language—Laplace transforms.

An intimate knowledge and feeling for math, rather than elevating the engineer to the clouds, enables him to cope with the quickly changing technical world. In addition, math and theory provide a starting point. Brute force "cut 'n plug" may have worked with light-bulb filaments but is quite inadequate for many of today's sophisticated systems and devices. As to having pictures of hardware in a text, why bother when it most likely will be outmoded in a few years? For example, in the M.I.T. Radiation Lab series, most of the ideas are still valid and useful, but the equipment pictured is of interest only to a historian.

Interesting also was Prof. Moore's concern about engineering graduates' lack of interest in such stimulating items as clothes washers, toasters, and house wiring. Let's face it, semiconductors, lasers, and radar are where the action is and, apparently, so are most of the job offerings. With regard to transportation, the recent special issue (April 1968) of the PROCEEDINGS OF THE IEEE indicated the engineer's concern with the problem.

The most curious comment in the article was the one stating that, as engineers, we have a culture (would you believe "tribal, cultural life"?) all our own. After trying to live down the common "engineer" stereotype, I find Prof. Moore suggesting that it be reinforced. Are we engineers so really different from the rest of humanity?

George J. Sehn
Epsco, Inc.
Westwood, Mass.

I am not sure if the following qualifies for the format of your correspondence section of IEEE SPECTRUM, but I could not resist commenting on Prof. A. D. Moore's recent article.

Eureka, we have an educator who has admirably stated the case against modern "engineering" education. I have only one criticism of Prof. Moore's article. He did not concisely state the cause of the condition he so eloquently portrayed. Professor Moore certainly recognizes the principle involved, for he mentioned it several times. However, I am afraid if it is not spelled out as an "invariant principle," some of the curriculum committees will miss the point.

I "discovered" the principle some years ago when, as an evening E.E. student, I tried to rationalize some of the topics we were exposed to, despite their irrelevance to electronics and telecommunications as I knew the fields. I termed the phenomena *academic incest.* The principle is simply stated: Those professional students who dictate how a student is to be prepared for industry have little or no industrial experience. To make up this "minor" deficiency, the faculties arrive at the curriculum by deductively developed concepts that are inbred within the academic world. Cyberneticists will recognize this inbreeding process as a feedback loop with, unfortunately, no filtering. When the feedback becomes positive, it results in a buildup that gives birth to the bandwagons Prof. Moore wrote about.

About the time the principle of academic incest was uncovered, a law of instruction was isolated that fits Prof. Moore's comments about "the Ph.D. mill." This law states, at least at the undergraduate level, that the effectiveness of instruction is *inversely* proportional to the number of degrees held by the instructor. There are two explanations of this law. Either the instructor is so enamoured with his advanced degrees that he wants to impress the students by losing them or, if he is a sincere instructor, his mathematical sophistication has created a communications barrier between himself and his students. I had the unfortunate experience of being exposed to both types.

While on mathematics, I refer to the modern presentation of math as x,y,z, math. Under x,y,z, math, you do not soil the student's pure mind with an explanation of the k's the poor student keeps stumbling over in calculus or differential equations. Nor do you attempt to relieve his bewilderment over the concept of the second derivative by mentioning acceleration. True, at higher levels there aren't such convenient physical illustrations, but it certainly would help to get the student's feet on the ground before entering the abstract.

As for bandwagon courses, our oldest

son recently brought home, from an "ivy league" college, his text on engineering mechanics. About 30 percent of the book concerned itself with mechanics. The remainder looked like a hybrid text of physical chemistry and particle physics. I could not help wondering what would happen when a graduate armed with this course attempted a P.E. exam. Needless to say, a P.E. cram course would be quite a shock!

I do not mean to imply by these remarks that there is no place for theory and the abstract. To return to a better balance, however, more colleges should establish separate programs of electrical sciences and electrical engineering, with appropriate ratios of theory and practice. This will enable industry to better select people for its particular needs.

The corporations certainly cannot be exonerated from what has happened in engineering education, with their strong emphasis on specialization and research. Therefore, to help, they must keep in mind that engineers, through their practical and economically feasible approaches, convert the ideas into the products creating today's record-breaking annual reports. A little recognition of these facts of life will go a long way. If "recognition" is interpreted as some of the glamour reserved for research, so much the better.

William L. Clements
W. Webster, N.Y.

Shoring the shortage

This letter is prompted by two items that appeared in the April issue of IEEE SPECTRUM: the comment on the decline of freshman engineering students in "Transients and trends" (p. 8); and the "Spectral lines" editorial (p. 45), which was partly devoted to the reason why, and which, furthermore, showed an unusual sensitivity to an understanding of why young people find it hard to be attracted toward careers in physics and engineering.

These comments do not pretend to be universal, but I think they are representative of a significant sector of public opinion and, although I was pleased to see that "these questions are receiving a great deal of organized attention, in many places," I think it is none too soon.

In my opinion, the following are significant factors in dispelling interest in scientific careers.

First, the majority of electrical engineers in the United States are working on projects whose end is to serve what is euphemistically misnamed "national defense." (We haven't been engaged in national defense since the War of 1812. If anyone doubts my "majority," count the employment ads.) There seems to be a sort of professional jingoism in certain engineering circles that, like lawyers and doctors, they shouldn't question the ethics of their clients. But what lawyers and doctors do helps their clients out of a situation without questioning how they got into it, whereas scientists are capable of getting their clients into trouble they weren't in before.

I find it hard to believe that, if there were more ethical considerations involved in the orientation of engineering careers, such a monopolistic position would be given to eliminating the "yellow peril."

Second, much of what remains of available engineering effort is devoted to whetting consumer appetites in an unholy alliance with advertising by making streamlined toasters, revolving quadruple headlights, and other totally useless "improvements" whose only function is to foster greed and posessiveness. Although in a professional publication such as IEEE SPECTRUM very little of this is reflected, in the real world of people looking for jobs, such activities represent an appallingly large market.

Finally, the great majority of available engineering careers are within companies with sales in the hundreds of millions of dollars, with employees in the tens of thousands, and with somewhere near a dozen subsidiaries. They are run by a board whose members, entirely aside from the fact that they are on the boards of several other similar companies, do not regard running the company as their principal occupation, and most certainly know nothing whatever about engineering. (There are exceptions, of course, Hewlett-Packard being among the most notable of them.)

Smaller, more closely controlled, more engineering-oriented companies without exception advertise for engineers thusly: ". . . 15 to 20 years' experience in. . . ." It may be that the competitive nature of United States business makes such a situation inevitable, but what is good financially may have a dreadful psychological impact, which makes it not worth the "price." In any case, let me say that there are no longer many who find attractive the thought of living in a golden anthill.

I am neither wise, experienced, nor presumptive enough to propose solutions for these problems. There are people whose entire job is to find such solutions, but I can offer some that won't work: more clever advertising won't; offering more money to starting engineers won't either (the legal profession has had a similar problem—in the last eight years, the starting salaries at Wall Street law firms has risen from $5500 to $15 000, but in spite of this the supply of young lawyers keeps dropping).

Such things as the shift in emphasis, seen at the IEEE International Convention this year, toward the solution of problems concerned with the world's resources, environment, and population will certainly help, as will the recently announced plans of several companies to locate small plants in slum and depressed areas. But I am sorry to say that, as far as I have been able to keep informed, engineers only took interest in these fields when the federal government decreed projects in the area and then set out with fistfuls of money to find engineers to help implement them.

I only hope that keeping in mind these considerations can help to form an effective policy to guide the future of our profession.

George E. Cleary, Jr.
El Socorro, Venezuela

A bigger brother

Your "Scanning the issues" department in IEEE SPECTRUM of June 1968 (pp. 96–97) deserves comment. Let me take it comment by comment, and thereby draw out the rather chilling philosophy embodied within it. I refer here to the item on "Transportation: Cosmic Needs."

The first is the statement, ". . .other important indexes such as direct social benefit to the average voter. The 'Great Society' on the other hand rates very high on those criteria of social usefulness. . . . How will we know [when] the 'Great Society' has arrived?"

Let me say that words and phrases such as these imply that it is the function of government to determine just how the resources of the nation will be utilized and in what direction its energies will be channeled. It really sounds like a free society of free individuals, with free enterprise as their economic motif, doesn't it?

Well, I'll suggest one means of determining when the "Great Society" has arrived. Just reread Orwell's *1984*, and when it doesn't sound far-fetched, you're there.

Next, "The goal is: to provide high-speed transportation between all of the major cities of the continental United States, *free* for all citizens, by 1985" (emphasis added). Shouldn't that date be 1984?

In any case, whatever happened to the idea that goods and services would find their own level in the marketplace? And does the operation of the railroads by the government (I exaggerate, but not much) really tend to give you confidence in their (or its) ability to perform such a function? How about the push for the electric car, when the steam car could do the job sooner, better, and with less disruption of the existing system? And if you think the projected system would be free, let's make a little bet.

Then ". . .Gibson's statement has a breathtaking appeal. . ." It all took my breath away—you'd better believe! No other comment. And, ". . .one must be emotionally obtuse not to be moved." Yep, enough written.

Last, but not least, "Of course, Gibson reflects, there was nobody with the required responsibility or authority to have done anything about it on a national scale even if adequate systems planning had been prosecuted immediately after World War II. . ." and "Furthermore, he sees it as apparent that such a national system must be planned and directed by the Federal government." This all has the philosophy that somehow, by pooling our ignorance in Washington, D.C., as we have always done, we can come up with the proper crystal ball to foresee such needs of the society.

What actually would happen, of course, is what always does when a bureaucracy takes over. The whole thing becomes hidebound. Innovation and change in response to changing conditions have seldom been the notable characteristics of Big Brother, whereas they have been characteristic of a free-enterprise market economy.

If we must bear the burden of having such economic illiterates or socialists around, at least let's not have them cluttering up an engineering society. And, for heaven's sake, let's not give them such a sympathetic review, if indeed, they are reviewed at all. It is because of philosophies like the one you demonstrated in this article that *1984* will really get here, even if it does arrive in 1985.

Lannon F. Stafford
Phoenix, Ariz.