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the cover

Loran-C navigational systems are capable of providing extremely accurate time synchronizations over long distances, as described in an article beginning on page 46. A ground-wave/sky-wave pattern typical of those encountered with Loran-C pulses is represented on this month's cover.

According to the old saying, "Too many cooks spoil the broth." In a defiant mood, we take pleasure in listing this month's authors—all from our Applied Electronics Division—Dr. Frank Arams, Dick Domchick, Ken Siegel, Bob Sleven, Jesse Taub, and Nick Worontzoff.

Progress In HF Superconducting Filters

Tunable filters with unloaded Q's in the order of several hundred thousand and bandwidths adjustable from less than 100 Hz to more than 20 kHz are now a reality through the application of superconductivity.

In December 1965, in this column, we first discussed superconducting RF filters. At that time we reported test results on a single-resonator lead filter operating in a bath of liquid helium at 4.2°K. This superconducting filter tuned from 6.3 to 21 MHz with measured values of unloaded Q greater than 500,000.

Since this initial milestone, considerable additional work has been performed on superconducting filters at AIL. Some of these accomplishments which we will briefly discuss here are:

- Operation of a superconducting filter with an HF receiver and evaluation of the improvement in RFI characteristics provided by the filter,
- Development of a multi-resonator, tunable superconducting band-pass filter,
- Development of a multi-resonator, tunable superconducting band-stop filter,
- Evaluation of higher temperature superconductors for operation with a closed-cycle refrigerator,
- Demonstration of a superconducting resonant circuit cooled by a compact closed-cycle refrigerator.

INTERFERENCE REDUCTION

The use of a single superconducting resonant circuit ahead of a typical HF receiver reduced the cross-modulation products by a factor of about sixty. By establishing a cross-modulation reference level, a measurement was made of the minimum frequency separation of two signals that would result in this reference level. The superconducting filter reduced the minimum separation from 3.45 MHz to 50 kHz. Intermodulation was improved by as much as 38 dB and, by reducing the noise level, the receiver sensitivity was improved by 23 dB. These RFI tests are described in detail in Reference 1. It must be emphasized that these results were obtained with a single, superconducting resonant circuit and would be greatly improved with a multi-resonator filter. The relative selectivity of one- and three-section superconducting filters is compared in Figure 1.

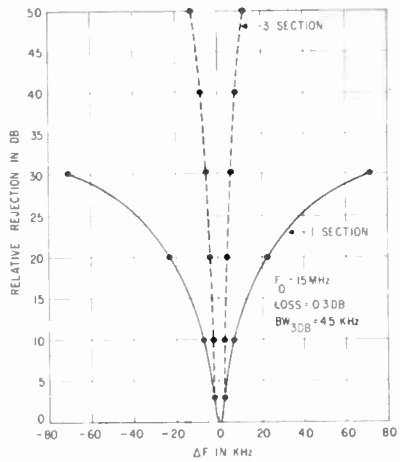

Figure 1. Relative rejection vs frequency deviation. Comparison of single and three section superconducting (4.2°K) lead band-pass filter

MULTI-RESONATOR BANDPASS FILTER

The first packaged multi-resonator superconducting bandpass filter had the following measured characteristics:

Tuning Range:	10 to 19 MHz
Bandwidth:	200 to 3800 Hz, adjustable
Insertion Loss:	1.5 dB maximum for bandwidth greater than 650 Hz
Number of Resonators:	3
Shape Factor:	60dB/3dB bandwidth ratio of 9:1

The demonstration of these characteristics required the solution of unique circuit theory problems as well as many practical mechanical problems. These problems were mainly due to the ultra-narrow bandwidths and the need to maintain constant center frequency while adjusting bandwidth, and constant bandwidth while tuning.

MULTI-RESONATOR BANDSTOP FILTER

The first packaged multi-resonator bandstop filter had the following characteristics:

Tuning Range:	8 to 21 MHz
Number of Resonators:	3
Rejection Notch:	1.9 kHz minimum at 40 dB points
Bandwidth:	10 kHz maximum at 3 dB points
Passband Insertion Loss:	0.3 dB at ±20 kHz from center frequency

The equal-element design was used for minimum loss and ease of tuning (Reference 2). The filter could be operated to reject one interfering signal with characteristics as above, or each resonator could be used individually to protect against three separate interfering signals.

"HIGH-TEMPERATURE" SUPERCONDUCTORS

The two filters discussed above used lead as the superconductor and were cooled by liquid helium to 4.2°K. The future of superconducting filters for practical field operation requires the cooling of the filter by a closed-cycle refrigerator. A relatively inexpensive refrigerator can provide substantial cooling capacity in the 10 to 15°K temperature range. Although a number of superconducting materials were considered, factors such as critical temperature, critical field, and availability indicated the selection of Nb_3Sn as a leading candidate. Figure 2 shows a plot of the unloaded Q of a self-resonant Nb_3Sn coil versus temperature. The Q remained nearly constant at about 500,000 up to 16°K. The feasibility of "high-temperature" RF superconducting filters was therefore established.

CLOSED-CYCLE-COOLED RESONANT CIRCUIT

The next step in achieving a practical superconducting filter required the cooling of the filter by a closed-cycle refrigerator. This milestone was reached with an Nb_3Sn coil on an alumina dielectric coil form. The alumina dielectric was an important factor since it combined an extremely low loss tangent with good thermal conductivity to enable high-Q operation and conduction cooling of the superconductor. This first superconducting filter cooled by a closed-cycle refrigerator provided an unloaded Q of over 300,000. In subsequent tests Q's of up to two million were measured.

This briefly indicates the present status of AIL's superconducting work which is still in progress. The results to date have been very satisfying and the goal of a field operational superconducting filter is now much closer to realization.

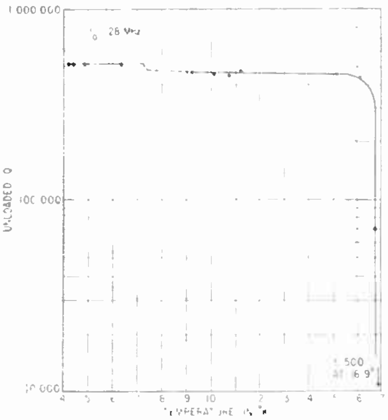

Figure 2. Unloaded Q of a self-resonant Nb Sn coil versus temperature

The work discussed here was supported by the U.S. Army Electronics Command, Fort Monmouth, New Jersey and the Department of Defense.

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1. F. R. Arams et al. "Superconducting Ultra-High Q Tunable RF Preselector," IEEE Transactions on Electromagnetic Compatibility, Vol EMC-9, Number 3, December 1967.

2. J. J. Taub and R. L. Sleven, "Design of Bandstop Filters in the Presence of Dissipation," IEEE Transactions on Microwave Theory and Techniques, Vol MTT 13, Number 5, September 1965.

IEEE spectrum

Spectral lines

The technology gap. Over the past few years, sales by European subsidiaries of U.S. firms have grown much faster than the general economy of Europe. Some European thinkers who find this trend disquieting ascribe it to a "technology gap"; there is a belief that advanced technology may be giving the U.S. a decisive economic superiority that will push Europe into a position of dependency or of second-class industrialism.

So far as I can discern from a perch on the edge of the stage, the technology gap is not just a consequence of the giant corporations that are a prominent feature of the American business scene. Europe, too, has large corporations—some of them backed by the resources of the state. Less noticed in the U.S. picture are the small but technologically important companies that are capitalized from personal savings and have aggressive technological leadership from engineers, or even scientists, who have founded them.

Within five miles of my house is a plant of one of the largest electronics companies in the world. It was started by two people. One of them was a man I knew. As a graduate student, he was told by the Physics Department that in hoping for a Ph.D., he was aiming too high. With an acquaintance and a shoestring, he started a company for making gas-filled point-to-plane rectifier tubes. As these became obsolescent, the little company very successfully turned its attention to the manufacture of vacuum tubes, diversifying later into the manufacture of whole systems. When I was an undergraduate, the failed graduate student had made enough money to retire on, and had returned as a self-supporting researcher to the university electronics laboratory, where he parked his Cadillac among the Chevrolets of the professors who had flunked him.

Within the same short distance of my house is a plant presided over by a man who would have been a contemporary in college if he had not dropped out. He went there to find out how to make sheets of material that would polarize light. When he felt sufficiently prepared to solve a problem that he knew had baffled some of the best brains for about a century, he left. He did solve it. What is more to the point of this discussion, he started a little company to manufacture the polarizer. With the profits, he found a method of producing a photograph in less than a minute. As president of the corporation that is based on his inventions, he is required by law to declare his holdings of stock in the formerly little company; at a recent valuation, that portion of his assets was worth well over 10^8 dollars. It may be unlikely that this feat will be duplicated by another dropout from a U.S. college, but is it even *possible* for a middle-class boy elsewhere?

Students, of course, are not the only ones who start companies. Professors do it, too, and within the aforesaid circle about my home are a number of such firms. One is the world's leading manufacturer of electrostatic high-voltage generators; another is a leader in the technology of processing light. Still another started with flash photography and has branched out into a variety of advanced instrumentation, particularly that needed for exploration underwater.

Though I can claim no real knowledge of business customs and methods in Europe, it seems that unsolicited innovation may be regarded as an inconvenience, which private enterprises and governments both tend to avoid. Also, I have the impression that an inventor there has little influence on, or contact with, the men who make the business decisions about his invention. By contrast, the environment in the U.S. favors the foundation of new businesses dedicated to innovation. They may be small enough so that one or two highly competent technologists who start a company can have a major influence on its development. Moreover, these technologists often own a significant fraction of the stock in the company, so that they retain their influence even when the organization grows large. As a generator of strength in technology, this phenomenon may be quite as important as corporate giantism.

Concern about the technology gap seems to be based on a fear that the situation is unstable—that the gap will widen without limit. Things may not be that bad. Even the name of the phenomenon recalls the "dollar gap." Twenty years ago, the flow of gold into the U.S. seemed as irreversible as Niagara Falls. Now, there is alarm about the rate at which gold is flowing the other way. New forces came into play to close that gap, and similarly countervailing forces may be closing this one. (1) Just *because* the dollar gap is gone, the taxes on U.S. corporations are structured to discourage investment in foreign branches. (2) Rising taxes on personal income may choke off the accumulation of risk capital by the "little rich," which has played a key role in the creation of the technology gap. (3) Many older universities in Europe are changing their patterns of being, and new ones are being founded, to increase the relevance of the curriculum to the ambient world. (4) A cause contributing to the gap has been the exertions, in U.S. industrial management, of many highly intelligent and ambitious men. Careers of this kind seem to have little appeal to the young Americans now in universities. If the brainy portion of the population turns its back on industry and commerce in the U.S. but not in some of Europe, then the technology gap will heal as quickly as did the dollar gap.

J. J. G. McCue

Authors

Raw energy sources for electric generation (page 34)

F. A. Ritchings received the M.E. degree in 1936 from Stevens Institute of Technology. He has been employed continuously since 1937 by Ebasco Services Incorporated, a firm of engineers, constructors, and utility consultants serving principally the investor-owned utility industry. From 1937 to 1951 he progressed with Ebasco from cadet engineer to project engineer to supervisory engineer, responsible for the execution of mechanical engineering and design of power plant projects. From 1951 to 1958 he was chief mechanical design engineer, in which capacity his technical and administrative duties encompassed the mechanical engineering and design of all steam electric stations being handled by Ebasco. From 1958 to 1959 he was assistant mechanical consulting engineer and then consulting mechanical engineer from 1959 to 1965. In the latter capacity he was responsible for the mechanical engineering aspects of all economic and technical feasibility studies undertaken by Ebasco for domestic and foreign utility clients. Since July 1965 he has been chief consulting engineer, in charge of the administration and overall technical direction of the consulting electrical, mechanical, civil, gas, and power systems engineers and their staffs.

Time synchronization from Loran-C (page 46)

L. Dennis Shapiro (M) is president and director of research at Aerospace Research, Inc., Boston, Mass. His activities have been primarily in the field of precise long-range timing and frequency synchronization by means of Loran-C transmissions and in the design and development of techniques and instrumentation toward this purpose. He was graduated from the Massachusetts Institute of Technology with the S.B. degree in electrical engineering in 1955 and the S.M. degree in 1957. In 1956 he was selected as a Summer Overseas Fellow at Marconi College, Chelmsford, England. He was a project scientist for the U.S. Air Force at the International Geophysical Year Station, Thule, Greenland, in 1957 and 1958, and participated in the nuclear testing program at Johnston Island in 1958. Prior to joining Aerospace Research, he was chief of the Space Research Section at Pickard and Burns, Inc., Needham, Mass.

Considerations in planning for reliable electric service (page 71)

Charles Concordia (F) has been with the General Electric Company since 1926, and is at present consulting engineer with the company's Electric Utility Engineering Operation. His work has been concerned principally with the dynamic analysis of electric machinery, interconnected electric power systems, and automatic control systems, including power system voltage, speed, tie-line power, and frequency control. In particular, he has been active in the application of both analog and digital computers as aids in the solution of these and other engineering problems. In 1942 he received General Electric's Coffin Award for his contributions to the analysis of wind tunnel electric drives. In 1962 he was awarded the Lamme Medal by AIEE for meritorious achievement in the development of electric machinery.

Mr. Concordia is the author of 88 technical papers and of a book on synchronous machines. He holds six patents in such diverse fields as centrifugal compressor aerodynamic design and power system transient overvoltages. He is a Fellow of the ASME and has served as national treasurer of the Association for Computing Machinery. He is chairman of the International Study Committee on Power System Planning and Operation of the International Conference on Large Electric Power Systems (CIGRE). He is currently a member of four IEEE committees.

International communications: the problems of progress (page 77)

T. B. Westfall, executive vice president of International Telephone and Telegraph Corporation, is responsible for the direction, coordination, and expansion of ITT's international telecommunications and domestic telephone operations. He joined ITT in October 1960 after serving the Grace Line, Inc., for nine years, first as assistant to the vice president and treasurer, and then as vice president and treasurer. He was appointed to the position of executive vice president in 1957. Prior to his association with the Grace Line he was director of audits with the General Accounting Office of the United States Government, where he served from 1946 to 1952. Earlier, he was a senior accountant with Price Waterhouse & Company.

Mr. Westfall is a native of Oklahoma. He holds the bachelor of science degree in business administration from the University of Oklahoma and the bachelor of laws degree from George Washington University. He served with the United States Army during World War II, from 1944 to 1946, and was honorably discharged with the rank of lieutenant (j.g.).

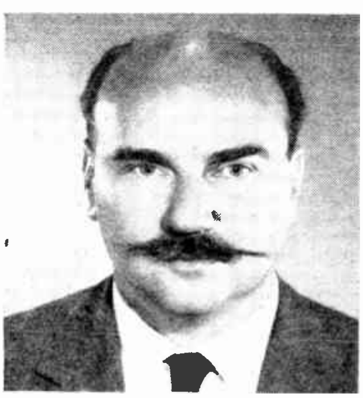
Mr. Westfall is a member of the bar in the District of Columbia and a certified public accountant in the State of Texas.

VITA—A sociotechnical challenge for the IEEE (page 82)

Harold L. (Buz) Hoffman (A) joined the IEEE SPECTRUM staff in April 1967, as assistant editor. A native of Brielle, N.J., he majored in electronics engineering at Monmouth College, West Long Branch, N.J., while concurrently working on the design and installation of marine electrical and electronics systems. Prior to joining the IEEE staff, he was assistant editor of *Test Engineering and Management* magazine, a publication devoted to aerospace environmental and reliability testing, and was agency managing editor for two Union Carbide publications, *Electric Welding Progress* and *Distributor Progress.*

Mr. Hoffman was formerly associated with Warsaw Studios, Inc., New York City, as a photographer. He has also served as a commercial consultant on color processing and printing, color laboratory design and procedure, and calibration and standardization of color analyzers for subtractive color printing. In addition, he has worked as a consultant on electronic studio lighting systems, special process photochemistry, applications of photography to law enforcement, photographic duplication, and audio–visual systems and procedures. At present he is serving informally as audio-visual systems and processes consultant to the IEEE Director of Educational Services in conjunction with the Institute's Slide-Tape Lecture Series.

The early history of electronics (page 90)



Charles Süsskind (F) received the B.S. degree from the California Institute of Technology in 1948 and the M.Eng. and Ph.D. degrees from Yale University in 1949 and 1951, respectively, all in electrical engineering. Prior to attending the California Institute of Technology he served on active duty with the United States Air Force from 1942 to 1945. He was a research associate and lecturer at Stanford University from 1951 to 1955 and then joined the faculty of the University of California, Berkeley, where he is now a professor of engineering science.

Dr. Süsskind has made extensive contributions to several branches of electronics, including microwave engineering, electron optics, and biomedical electronics. He edited *The Encyclopedia of Electronics* (New York, Reinhold Publishing Corp., 1962) and was coauthor (with Marvin Chodorow) of *Fundamentals of Microwave Electronics* (New York, McGraw-Hill Book Company, Inc., 1964). His critical study, *Popov and the Beginnings of Radiotelegraphy* (San Francisco Press, Inc., 1963, based on a paper that had been published originally in the October 1962 issue of the PROCEEDINGS OF THE IRE) created an international controversy. He has contributed a large number of technical and historical articles to IEEE and other journals. One of his current projects, a comprehensive history of radar, is supported by a grant from the National Science Foundation.

Raw energy sources for electric generation

It is predicted that by 1985 nuclear sources will provide more than 40 percent of the total raw energy for electric power generation in the United States, ranging from about 25 percent in the Southwest to more than 70 percent in New England

F. A. Ritchings *Ebasco Services Incorporated*

The energy picture in the United States, through the year 1985, is outlined in this article. The forecasts made are based on a number of factors, including economics, present and future estimates of fuel availability, relative plant size, transportation, and air pollution considerations. On a national basis, it is predicted that the consumption of all forms of raw energy for electric generation will increase substantially from now to 1985, with nuclear energy exhibiting the most dramatic absolute and relative gains.

The economy of every country in the world depends upon the conversion of raw energy into useful work. Those countries with the higher rates of energy conversion per capita and the higher conversion efficiencies have the higher levels of economic activity.

Figure 1, derived from UN statistics for 1965, shows the relationship between gross national product expressed in U.S. dollars and the raw energy consumption per capita for several countries, including the United States. It is no accident that the United States, which has the highest standard of living, the highest gross national product per capita, the highest average income per capita, and the highest industrial production rate per capita, also has the highest raw energy consumption per capita. The United States, with about 6 percent of the world's population, consumes about 34 percent of the raw fossil and nuclear fuel and hydroelectric energy converted to useful work in the world.

U.S. energy consumption

This article is concerned primarily with the energy picture in the United States. Figure 2 shows the sources of raw energy consumed for all purposes including electric power generation, all forms of transportation, household and commercial uses, and industrial and other miscellaneous end uses. Total U.S. energy requirements were about 40 quadrillion (40×10^{15}) Btu (42×10^{18} joules) in 1955 and about 54 quadrillion Btu in 1965, an increase of 35 percent or an average annual increase of about 3.1 percent.

Total U.S. energy consumption for 1966 was 57 and preliminary data indicate the 1967 consumption was about 60 quadrillion Btu or an average annual increase of about 4.5 percent during the past two years. Thus recent history indicates that energy use is accelerating.

We predict that the increase from 1965 to 1975 will be at an annual rate of 4.0 percent, resulting in 1975 energy consumption of about 80 quadrillion Btu, or about 48.5 percent more than in 1965.

It is difficult to believe that the present rate of expansion will continue indefinitely and we think that the annual rate of increase in energy consumption after 1975 will be closer to the historical average. We predict that the increase in the ten-year period from 1975 to 1985 will be about 3.3 percent per year, resulting in an energy consumption of 110 quadrillion Btu in 1985.

Between 1955 and 1965 the percentage of raw energy requirements provided by oil and oil products and by hydro resources remained relatively constant. The percentage of total energy requirements provided by coal has decreased by about the same amount that the percentage provided by natural gas has increased. This is the historical record. We predict that the raw energy requirements in the future will be provided by these sources in the percentages indicated in Fig. 2 for 1975 and 1985. By 1985 nuclear energy will provide about 14 percent of our total annual energy requirements.

The reason for these changing relationships is discussed later, but note that the percentages shown in Fig. 2 apply to increasing total energy requirements. Thus, although coal provided about 30 percent of the 40 quadrillion Btu required in 1955, we predict that it

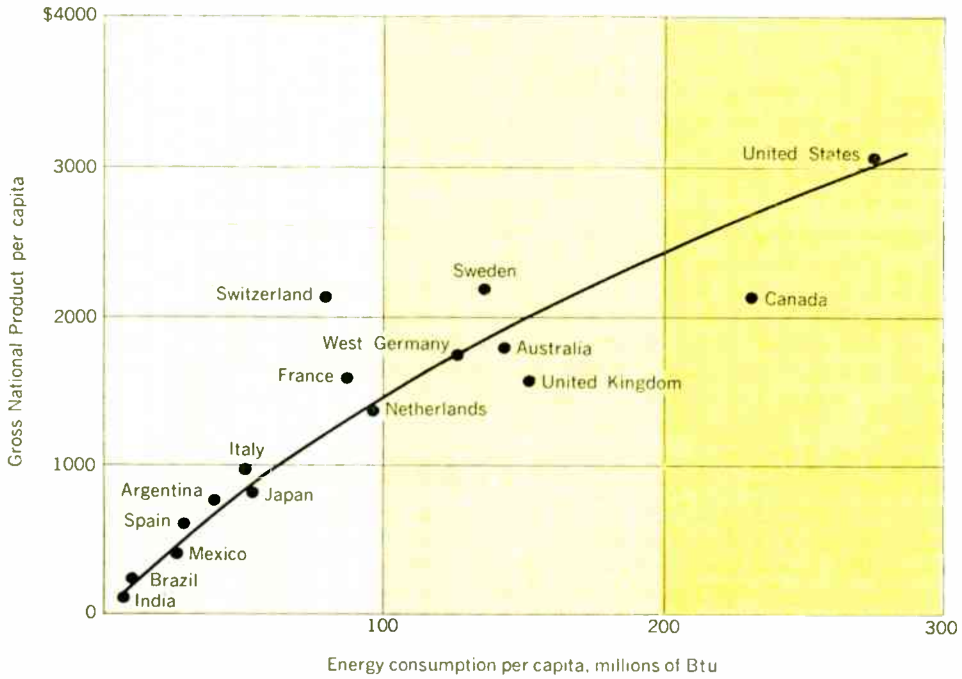
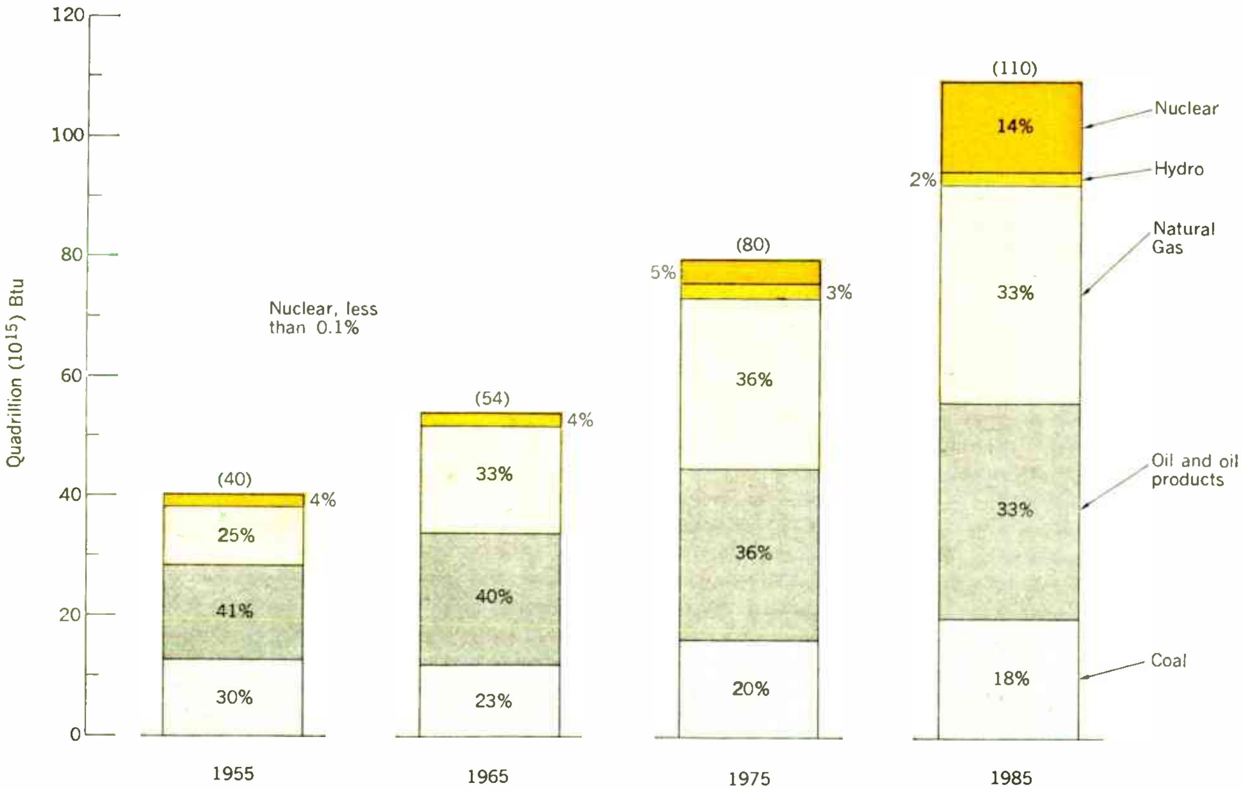


FIGURE 1. Relationship between gross national product and energy consumption, both on a per capita basis.

FIGURE 2. Sources of raw energy consumed in the United States for all purposes.



I. U.S. energy consumption by major use categories, trillions of Btu

	Coal	Natural Gas	Oil and Oil Products	Hydro	Nuclear	Total
Household and commercial						
1955	1 775	2 850	4 001	—	—	8 626
1965	625	5 534	5 634	—	—	11 793
1975	460	8 430	6 700	—	—	15 590
1985	400	11 650	7 800	—	—	19 850
Industrial						
1955	5 849	4 675	3 329	—	—	13 853
1965	5 689	7 685	4 141	—	—	17 515
1975	7 095	12 200	5 370	—	—	24 665
1985	8 160	14 200	6 800	—	—	29 160
Transportation						
1955	474	254	9 109	—	—	9 837
1965	19	518	12 184	—	—	12 721
1975	20	700	18 000	—	—	18 720
1985	20	800	23 300	—	—	24 120
Electric energy generation						
1955	3 484	1 194	512	1497	—	6 687
1965	5 880	2 399	743	2050	38	11 110
1975	8 520	3 770	940	2580	4 260	20 070
1985	11 300	4 850	1 070	3200	15 500	35 920
Miscellaneous						
1955	123	260	572	—	—	955
1965	145	—	507	—	—	652
1975	145	—	710	—	—	855
1985	120	—	830	—	—	950
Total gross energy input						
1955	11 705	9 233	17 523	1497	—	39 958
1965	12 358	16 136	23 209	2050	38	53 791
1975	16 240	25 100	31 720	2580	4 260	79 900
1985	20 000	31 500	39 800	3200	15 500	110 000

will provide only 18 percent of the 110 quadrillion Btu required in 1985.

Although the relative share of the energy market satisfied by coal will decrease, the total tonnage of coal consumed in 1985 will be about 65 percent greater than it was in 1965. The 14 percent of the 110 quadrillion Btu predicted to be furnished by nuclear sources in 1985 is more energy than was furnished by coal in 1965.

Table I shows the total U.S. energy consumption and its division into classes of use in 1955 and 1965 and our predictions for 1975 and 1985. Each energy source has particular attractiveness in certain markets because of its inherent characteristics. The convenience of natural gas for household and commercial use accounts for its very large increase in that market, and the inconvenience of coal for domestic purposes accounts for its decline in that market.

For practical purposes the entire increase in transportation energy requirements will be met by oil and oil products because economics favor that energy source. Electric energy will require increasing amounts of coal, oil, hydro, and nuclear energy sources, but the greatest increase will be in nuclear energy.

Figure 3, which is derived from Table I, shows the breakdown of U.S. energy consumption into major use categories. We are primarily concerned here with electric energy. Figure 3 shows that electric energy generation accounted for 16.8 percent of total U.S. raw energy consumption in 1955 and 20.6 percent in 1965; it is expected to account for almost one third of total U.S. raw energy consumption in 1985.

During the 1955–1985 period the percentage of total energy requirements for all other major uses will decline. To those directly involved in or associated with some phase of the electric utility business this is a significant forecast.

What will cause the changing pattern of raw energy consumption?

FIGURE 3. Energy consumption in the United States, classified by major use categories.

Electric energy generation

Figure 4 illustrates the increase in electric energy generated by the total electric utility industry, both public and private, and the electric energy consumption per capita. The total electric energy generated was 547 billion (547 × 10^9) kWh in 1955 and 1055 billion kWh in 1965 or almost double that of 1955. There is no reason today to believe that this same rate of increase will not continue for the immediate future, resulting in a total generation of 2020 billion kWh in 1975. Some day a degree of saturation may be reached but there is no way now of predicting when or if this will occur. We estimate that the rate of increase after 1975 will be slightly less than the rate of increase from 1955 to 1975, and on this basis we estimate a total generation of 3700 billion kWh in 1985.

It is possible, of course, that electric generation in 1985 will actually be more or less than this value, and a more refined prediction can be made five or more years from now. The timing is relatively unimportant.

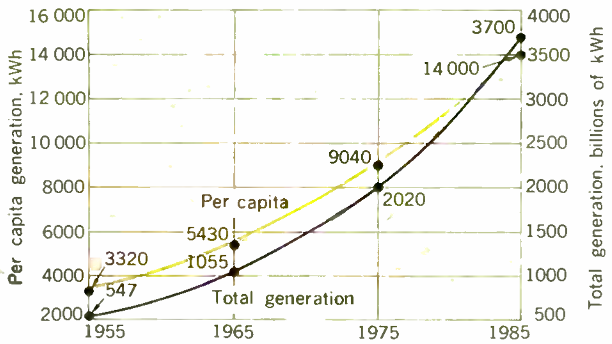


FIGURE 4. Electric energy generated by the total utility industry (excludes industrial generation).

Figure 4 also shows the electric generation per capita. This was 3320 kWh in 1955, increasing to 5430 kWh in 1965, and we predict over 9000 kWh per capita in 1975 and 14 000 in 1985.

These historical data and future predictions indicate that electric energy generation will, between 1965 and 1985, increase 250 percent from 1055 to 3700 billion kWh per year, and that electric energy generation per capita will increase 150 percent from 5430 to 14 000 kWh per year. At the same time, the total energy use will increase 100 percent from 54 to 110 quadrillion Btu per year and total energy use per capita will increase 50 percent from 280 to 425 billion Btu per year. During the 1965-to-1985 period the population of the United States will increase by only 35 percent, from 195 to 265 million.

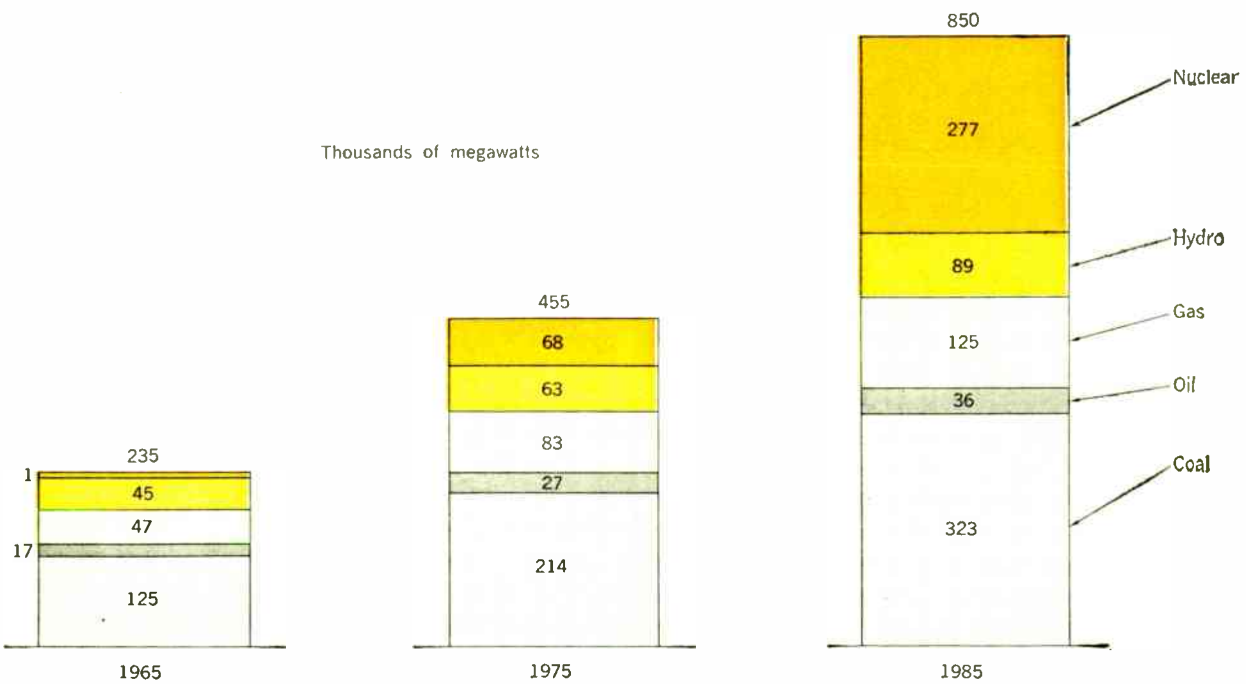
Of significance and not often cited is the prediction that electric energy generation per capita will increase at a rate three times that of total energy requirements per capita. This trend is indicative of the degree to which electric energy is preferred by the ultimate consumer. The pattern is expected to persist, provided the utility industry can continue to make electric energy available at costs competitive with other forms of energy and with the required reliability of service.

So far I have related the U.S. energy consumption to world energy consumption and have related the energy required for all purposes to the energy required for electric generation in the United States.

The remainder of this article is related only to electric energy generation, to the raw energy sources available, and to the degree to which each energy source will be used in the future for electric energy generation in the United States. Finally, estimates are presented of future raw energy consumption for electric generation in each of the nine U.S. Census Divisions.

Figure 5 shows the total installed primary generating capacity of the U.S. electric utility industry in 1965

FIGURE 5. Total U.S. utility generating capacity.



and our predictions for 1975 and 1985 to make available the generation of 2020 billion kWh in 1975 and 3700 billion kWh in 1985. The generating capacity is here classified in accordance with the primary fuel for which the installation is designed. The division of fossil-fueled plants into coal, oil, and gas plants may not be exact historically, because no accurate figures are available, but the values given are approximately correct.

The hydro capacity includes conventional hydro only and does not include pumped storage, because pumped storage is not a primary source of electric energy generation. Pumped storage units provide capacity and energy to meet peak load requirements but the electric energy generated originates with generation by fossil- or nuclear-fueled plants.

Note that during the 20-year period from 1965 to 1985, less than half of the working life of engineers graduating from school today, the total installed gen-

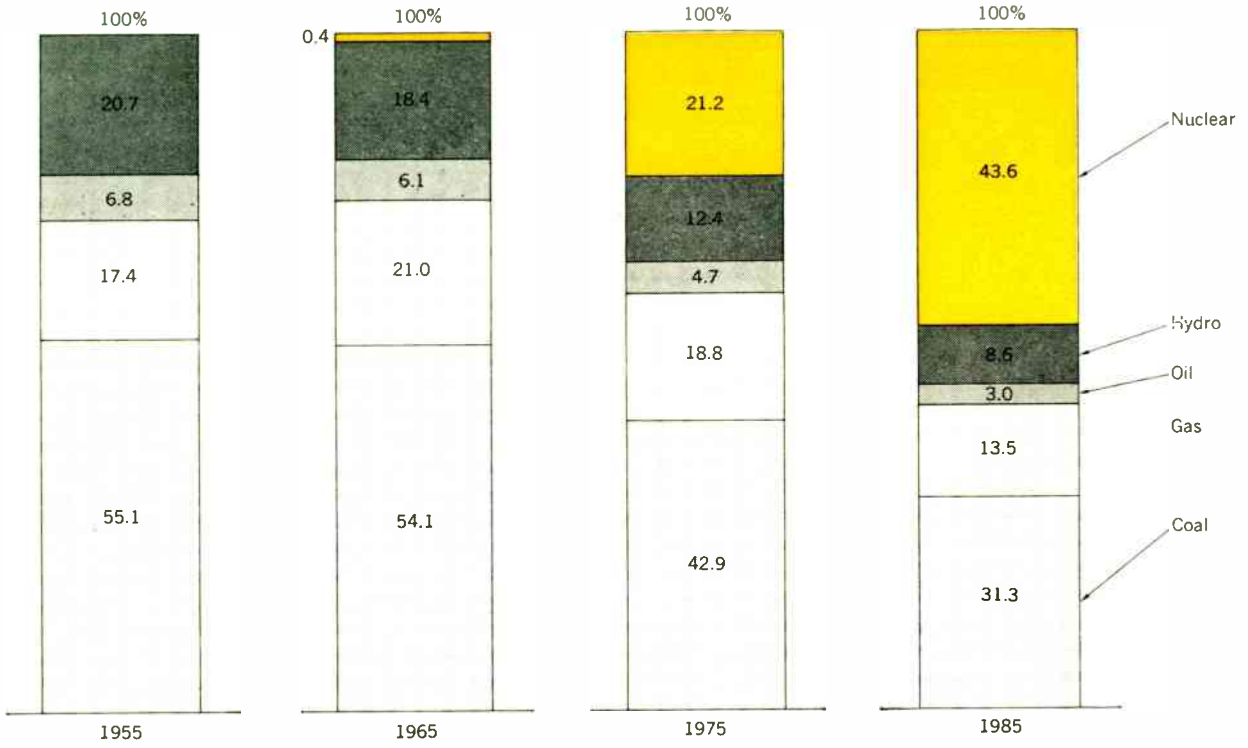
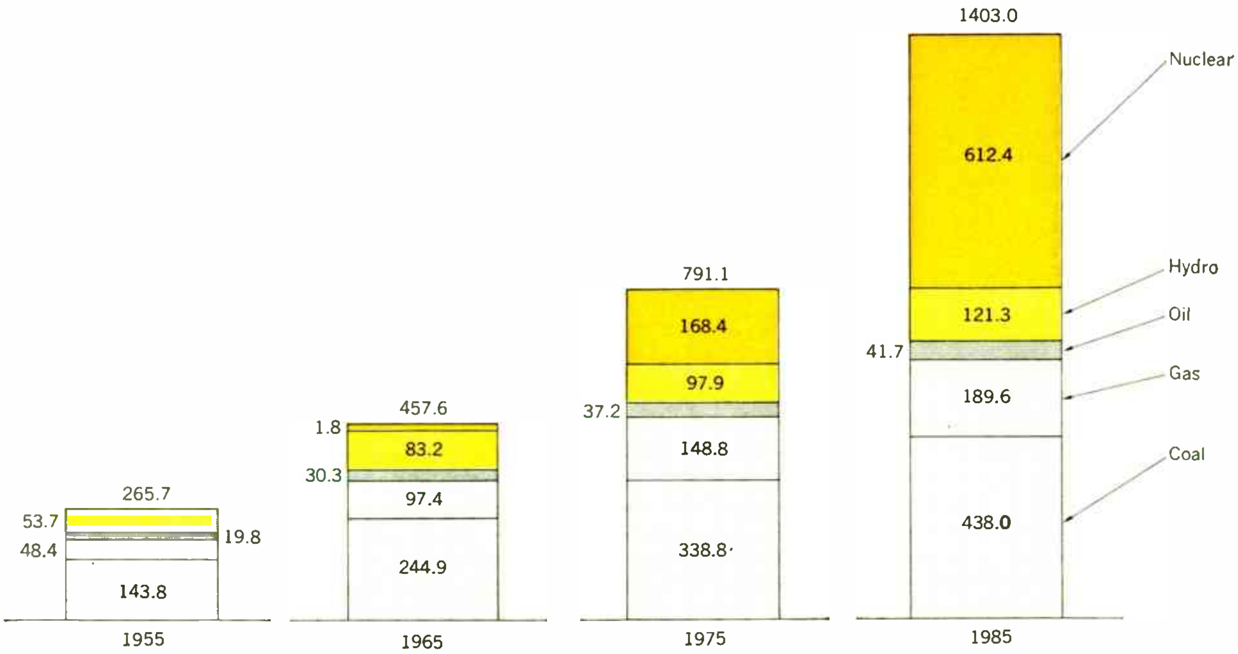


FIGURE 6. Raw energy for U.S. electric generation, expressed as a percentage of total generation.

FIGURE 7. Raw energy for U.S. electric generation, expressed in millions of tons of coal (equivalent).



erating capacity will increase by about 615 000 MW or more than 2½ times the capacity in service during 1965.

The increase will be made up of 198 000 MW in coal, 19 000 MW in oil, and 78 000 MW in gas-fired units, plus 44 000 MW in conventional hydro and 276 000 MW in nuclear generating units. By 1985 the nuclear generating capacity alone will be about 43 000 MW more than the total installed capacity in fossil-fueled and hydro units in 1965. Figure 6 shows the relative percentage of electric generation provided by each raw energy source.

Although the consumption of all fossil fuels will increase in quantity, each will provide a decreasing percentage of electric requirements. We estimate that during the 1965 to 1985 period, coal's share of the electric generating market will decline from 54.1 to 31.3 percent; natural gas will decline from 21.0 to 13.5 percent; oil will decline from 6.1 to 3.0 percent. Hydro energy will decline from 18.4 to 8.6 percent and, at the same time, nuclear energy will increase from an insignificant 0.4 to 43.6 percent of the total electric energy market.

In making these predictions we have considered the many factors affecting the selection of fuels, including availability, probable fuel price, energy uses competing with electric generation for the available fuel resources, and the probable economic break-even cost among fuels for equal electric energy costs.

Figure 7, derived from Fig. 6, illustrates the raw energy sources used to generate the 547 billion kWh in 1955 and 1055 billion kWh in 1965 and our predictions as to the raw energy sources that will be required to generate 2020 billion kWh in 1975 and 3700 billion kWh in 1985. To simplify the chart and put the requirements of each energy source in perspective, all raw energy consumptions have been shown in equivalent tons of coal.

II. Annual average capacity factor by energy sources

	1955	1965	1975	1985
Year-end capacity, thousand MW				
Coal	60	125	214	323
Gas	22	47	83	125
Oil	8	17	27	36
Hydro	25	45	63	89
Nuclear	0	1	68	277
Total	115	235	455	850
Energy generated, billion kWh				
Coal	302	571	865	1155
Gas	95	222	380	500
Oil	37	65	95	110
Hydro	113	193	250	320
Nuclear	0	4	430	1615
Total	547	1055	2020	3700
Average annual capacity factor, percent				
Fossil (coal, gas, oil)	58.3	53.5	49.3	42.9
Hydro	53.8	51.3	46.1	42.0
Nuclear	—	42.3	80.0	70.0
Weighted average	56.7	53.6	52.3	51.3

These equivalent tons of coal are based on 12 000 Btu per pound of coal and a net station heat rate of 11 600 Btu/kWh in 1955, 10 400 in 1965, 9400 in 1975, and 9100 in 1985. Note that the consumption of all fossil fuels will continue to increase as will the generation by hydro. The most spectacular increase, however, will be in nuclear energy. Because of the predicted nuclear generation, the consumption of fossil fuels will increase during the next 20 years but at a much lower rate than in the past.

The percentage increase in aggregate consumption of fossil fuels during the 1965-to-1985 period will be only about as great as the percentage increase during the 1955-to-1965 period. The increase in hydro as an energy source from 1965 to 1985 will be somewhat less than from 1955 to 1965 primarily because of lesser availability of remaining sites that can be economically developed. Note also that by 1985 nuclear energy used for electric generation will be 130 percent greater than the total energy from all sources used for electric power generation in 1955 and 34 percent greater than the total energy from all sources used for electric generation in 1965.

Thus the greatest influence on energy resource planning for the future is a very rapid emergence of nuclear energy as a prime and economic raw energy source and one that will by 1985 account for a greater percentage of electric generation than any other raw energy source.

Capacity versus energy

The electric utilities have made strenuous efforts to increase annual capacity factor, principally by increasing off-peak loads. Because of geographic, climatic, and other conditions, some utilities have been more successful than others. However, the national average capacity factor continues to sag. It was about 56.7 percent in 1955 and 53.6 percent in 1965. If this long-term trend continues, the national average annual capacity factor would be about 50 percent in 1975 and 47 percent in 1985. Our estimates of the total installed generating capacity assumed that this long-term trend will be arrested and thus the national capacity factor will be about 52 percent in 1975 and 51 percent in 1985. We have assumed that this improvement from the historic trend will result from such things as more electric house heating, more all-electric homes, more irrigation pumping, and, hopefully, electric automobiles.

Table II shows the generating capacity installed, the kWh generated, and the annual capacity factor for each energy source historically for 1955 and 1965 and our projections for 1975 and 1985. The decreasing capacity factor for fossil-fueled generating capacity will result from the higher capacity factors on nuclear units because of their lower incremental electric energy costs. By 1985, as nuclear units become a larger percentage of installed capacity, and assuming that the overall national average capacity factor will be about 51 percent, the capacity factor on nuclear units will start to come down. The decreasing capacity factor on hydro will result from hydro capacity becoming a lesser percentage of the total capacity, an increased retention of pondage for peaking purposes, and possibly by greater restrictions on drawdown of water levels because of increased emphasis on recreational and stream-flow augmentation values.

Availability of fossil fuels

Our appetite for raw energy in all forms is increasing. Our only renewable energy source of any significance is hydro. All fossil-fuel consumption decreases the remaining reserves. Long-range energy resource planning requires that we consider the availability of fuel resources since fuel price and availability are related. In the case of natural gas, the indicated limitation of reserves and, hence, gas availability as a boiler fuel will result in substantially increased prices.

Coal. Let us consider coal first, because coal today provides about 54 percent of the raw energy for electric generation and 23 percent of the total national energy requirements for all purposes. Coal is our most abundant fuel. The recoverable coal reserves of the U.S. are estimated to be 830 billion tons, assuming 50 percent recovery, with about 30 percent of the total reserves being east of the Mississippi River. We consider these estimates to be too high in terms of coal that can be mined with the technology and equipment that will probably be available in the foreseeable future and at prices reasonably comparable to present-day coal costs. These estimates by others probably include coal in seams too thin to mine economically, as well as coal seams that would not be mined because of poor floor or roof conditions, coal of poor characteristics, and seams too deep to be worked economically. Some authorities believe that the economically recoverable coal reserves are about 415 billion tons; even that amount is 900 times the 1965 consumption. We are not concerned about the availability of a fuel for which we probably have 900 years' reserve at the present rate of consumption.

Gas. Natural gas, however, is a different story. Natural gas industry sources have estimated the total original U.S. gas reserves to be 1290 trillion cubic feet; about 314 trillion cubic feet have been produced or extracted through December 1966, leaving 976 trillion cubic feet of reserves remaining. Of that total, gas industry sources class 286 trillion cubic feet as proven reserves, plus 300 as probable, plus 210 as possible, and 180 trillion cubic feet as speculative reserves. The proven reserves have increased each year, but not as much as the increase in natural gas consumption. The ratio of proven reserves to annual production was 22.1 years in 1955, 20.14 years in 1960, and 17.63 in 1965; at this rate, the ratio will decline to 13.0 years by 1975 and 12.0 years by 1985. While coal reserves are adequate for something like 900 years at present rates of consumption, proven gas reserves are available for only 17 years at the 1965 rate of consumption. If the 976 trillion cubic feet of proven, probable, possible, and speculative reserves are actually available, then gas reserves will be equal to less than 60 years' supply at the 1965 rate of production.

To achieve a reserve-to-production ratio of only 12 years in 1985 the proven gas reserves must be progressively increased from the present "discovery" rate of 20 trillion cubic feet per year to 35 trillion cubic feet per year by 1985. No one can predict with accuracy just how much the natural gas proven reserves will increase, but all indications point to a declining reserve-to-production ratio. This situation may be alleviated to some extent by increased imports of gas and possibly by generation of pipeline gas from coal. Because of the attractiveness and advantages of natural gas for higher-priority use we believe that the normal relationship of price to availability will result in higher gas prices where gas is used as a boiler fuel, such as in the South and Southwest. The gas price, as determined or affected by availability, will result in other energy sources becoming economic in the future for electric energy generation. We predict that this will result in nuclear energy becoming economic for large base load units in the South and Southwest.

Oil. Oil accounts for only a small percentage of total U.S. electric generation, about 6.1 percent in 1965. The bulk of the oil consumed for electric energy is in the coastal areas, where oil can be delivered by tanker. The added cost of transporting oil inland generally limits its use for electric generation purposes to the coastal states, where it appears that the oil price is made to be competitive with coal. The total U.S. crude oil requirements in 1965 were 3.3 billion barrels and the proven U.S. reserves were 31.4 billion barrels, resulting in a reserve-to-production ratio of only 11.0 years, or less than that of natural gas. By 1985 the total annual U.S. crude oil requirements are estimated to be 5.3 billion barrels and proven reserves are estimated to increase to 40 billion barrels, giving a reserve-to-production ratio of only eight years—again less than gas. For electric energy resource planning, however, we are not too concerned with U.S. oil availability or reserves alone, since oil is burned for electric energy purposes primarily along the East and West Coasts. With larger and larger tankers being built, the oil will come from worldwide oil reserves and not just from the United States.

Other fuels. In our predictions of availability of coal, gas, and oil, I have omitted other potential sources of energy. One potential oil source is oil shale, from which oil or gas can be produced. However, we do not expect to see an extensive shale oil industry develop during the limited period of these projections, that is, not before 1985. Estimates of U.S. shale oil reserves, principally in Colorado and Utah, vary from 100 to 500 billion barrels, or 3 to 15 times the proven U.S. oil reserves.

Another source of oil is the tar sands in Canada, but only time will tell the extent to which these reserves will form the basis of an economic raw energy source for electric generation.

Natural gas supplies may be augmented by the production of pipeline gas from coal. Again, however, we do not expect that significant quantities will be produced before 1985, at least at prices that can compete with other energy sources for electric energy production.

Hydro

Hydro is our only renewable energy source of any significance. In 1965 the installed hydro capacity was about 45 000 MW. Since it has been estimated by the Federal Power Commission that the total hydro potential, excluding Alaska, is about 156 000 MW, the available resources are probably about 28 percent developed today. Of the 111 000 MW remaining potential, about 60 percent of the sites are located in the mountainous regions of the West. The sites susceptible to economic development are becoming more scarce, and other water uses (such as for recreation, irrigation, navigation, low-flow augmentation, and flood control) are becoming increasingly important. We believe that much of the remaining hydro development in the U.S. will be as a part of multipurpose water resource developments. Combined with the relative economics of nuclear generation, these factors will, in our opinion, reduce the growth rate of hydro. We estimate that the installed hydro capacity will increase in the next 20 years only as much as it increased during the past ten years.

Nuclear energy

As of January 1968, the nuclear generating capacity in service or on order for operation through 1970 was about 12 700 MW, with an additional 40 400 MW scheduled for operation by the end of 1975. Since our data come from utilities, manufacturers, and published announcements it is possible that I have failed to include some installations that are definitely planned. This sudden emergence of nuclear energy as a source of electric generation indicates that it has become a yardstick for comparison before decisions on large generating units are made.

With few exceptions these units are located in the higher-fuel-cost areas, where fossil fuel (whether coal, oil, or gas) must be transported long distances to the plant site. As of January 1968, commitments could still be made for nuclear units scheduled to operate as early as late 1973. We estimate that an additional 15 000 MW of nuclear capacity will be purchased, bringing the 1975 total to 68 000 MW.

The electric utility industry will use whatever raw energy source will provide the lowest delivered electric energy costs. The choice of energy sources will, in the future as in the past, be the result of economic comparisons among available alternates.

Investment requirements

Figure 8 illustrates the investment requirements for the first nuclear, coal, oil, or gas generating unit at a new site. The investment requirements shown are not applicable to any specific installation, since they are based upon national average site conditions and site requirements, labor costs, labor productivity, utility client desires, and schedules.

They exclude the cost of land, but they are based upon late 1967 market conditions for equipment pricing and include estimated escalation of material and labor for mid-1974 initial operation and also interest during construction. For any specific installation the investment requirements could be well above or well below these values; however, estimates based on national average conditions are useful for estimating the average national impact of nuclear energy.

Note that in dollars per kilowatt of maximum net generating capability, investment requirements for all types of thermal units decrease with increase in size, but investment requirements for nuclear plants decrease more rapidly than for those using fossil fuels. For example, the difference in investment between a coal and a nuclear generating unit averages \$60 per kW at 400 MW, \$58 per kW at 600 MW, \$50 per kW at 800 MW, and \$41 per kW at 1000 MW. We expect that this decreasing differential will continue for units larger than 1000 MW. Thus, the larger the unit the more likely it will be that nuclear energy is the economic choice. This fact is significant, since we believe that the largest units required by the utility industry will be about 1250 MW by 1974, 1500 MW by 1976, 1650 MW by 1977, 2000 MW by 1979, 2500 MW by 1982, and possibly 3000 MW by 1984 or 1985.

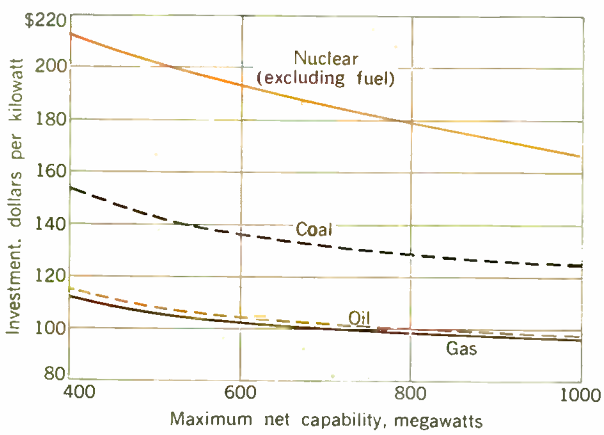
Fuel costs

Table III, the end result of numerous studies, shows the average cost of coal, oil, and gas required today to provide the same electric energy costs at the high side of the plant main power transformers as can be obtained with nuclear. These are then "break-even" costs. These values are based on the investment estimates given in Fig. 8 and on nuclear fuel-cycle costs, which result in a long-term average nuclear fuel cost, including capital charges, of 1.45 mills per kilowatthour generated.

Note that for a 1000-MW unit and based upon national average investment requirements, the break-even delivered coal cost ranges from 23.1 cents per million Btu for an 80 percent capacity factor and 10 percent fixed charge rate to 27.3¢/MBtu for a 67.5 percent capacity factor and a 13 percent fixed charge rate, a difference of only 4.2¢/MBtu. For oil or gas, the spread is about 6.6¢/MBtu above a base of about 28.0¢/MBtu.

The national weighted average cost of all fossil fuels delivered to the plant site (as published by the Federal

FIGURE 8. Capital investment requirements for 1974 operation, assuming average site conditions and labor conditions (for the first unit on a new site).



III. Fossil fuel cost required to break even with nuclear energy, cents/MBtu

Maximum Net Capability, MW:	450		640		1000	
Capacity factor:	67.5%	80%	67.5%	80%	67.5%	80%
10% fixed charge rate						
Coal	27.8	25.5	27.0	24.7	24.9	23.1
Oil	35.5	32.0	33.2	30.1	20.7	28.0
Gas	35.1	31.6	32.9	29.7	30.6	27.9
13% fixed charge rate						
Coal	31.1	28.2	30.0	27.3	27.3	25.1
Oil	40.8	36.5	38.1	34.2	34.6	31.3
Gas	40.2	36.0	37.4	33.5	34.6	31.2

Power Commission) was 27.7¢/MBtu in 1950, 26.2¢/MBtu in 1960, and 25.2¢/MBtu in 1965. The long-term trend of average fossil-fuel cost has been downward at the rate of about 1.5¢/MBtu each ten years. We expect that the trend of coal prices will continue to be downward because we have adequate reserves and because improvements in mining techniques will continue; and through the use of larger cars, larger trains, and unit trains dedicated to specific service, the trend of coal transportation costs will be downward despite recent increases. We expect that oil prices will continue to be competitive with coal where oil can be delivered by tanker to coastal plants.

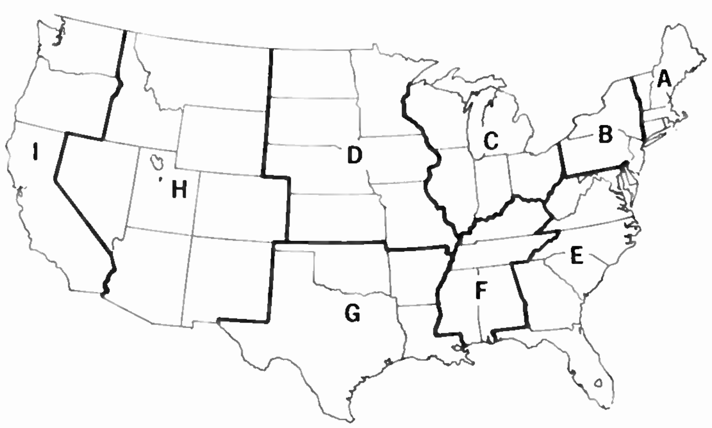
It is significant, however, that the 1965 national average delivered fuel price is between the minimum and maximum cost of coal to break even with nuclear energy, which probably explains why the bulk of the nuclear units now in service, on order, or announced are in the areas in which coal has been the primary source of electric energy generation.

Boiler fuel is a relatively low-priority use for natural gas, which is in increasing demand as a petrochemical raw material and for uses of convenience. As demands for gas other than as boiler fuel increase and as the ratio of proven reserve to annual production decreases, it is reasonable to expect that the lessening availability of that fuel will result in higher prices. This will make nuclear sources more competitive with gas in those southern areas of the country in which natural gas has been the traditional source of electric energy generation.

The larger the unit the lower is the cost of fossil fuels required to break even with nuclear generation. This cost is 2.4 to 3.8¢/MBtu lower for a 1000-MW unit than for a 400-MW unit. There is no indication today that plant investment per kilowatt of capacity will not decrease further as unit sizes are increased. Considering that nuclear technology is still relatively new as compared with the burning of fossil fuels, we expect that nuclear generating plant investment will decrease at a more rapid rate than will the investment in fossil fuel plants as unit sizes increase beyond 1000 MW.

We expect that nuclear fuel costs will also decrease slowly as competition develops for the many processes and procedures required to convert the raw ore to a finished fuel element and in the reprocessing of spent fuel.

FIGURE 9. United States Census Divisions.



One other factor that will tend to favor nuclear energy over coal is air pollution abatement. The Air Quality Act of 1967 requires that each state adopt air quality standards and enforcement plans for each type of air pollutant for which the Secretary of Health, Education and Welfare (HEW) publishes air quality criteria and control technology data. We are not sure what air quality criteria will be issued, but we believe they will have a serious impact on coal- or oil-fired generating units. We believe that such units will either have to burn the higher-cost, low-sulfur fuels or provide some means of reducing the SO_2 content of stack gases before they are discharged into the atmosphere. Present indications are that the simpler SO_2 removal systems, without provision for sulfur product recovery, may require an investment of $7 to $8 per kilowatt and result in an owning and operating cost equivalent to a fuel cost of 3 to 4¢/MBtu. Air pollution regulations requiring the installation of equipment, and having the effect of increasing fossil fuel prices by 3 to 4¢/MBtu, will further accelerate the trend to nuclear energy sources in the traditionally coal- and oil-burning areas.

The present-day comparative economics between fossil and nuclear fuels, the probable narrowing difference between nuclear and fossil generating unit investment as unit sizes increase, the probable reduction in both coal and nuclear fuel costs, the probable increase in natural gas costs, and the probable continuation of oil prices competitive with coal are factors that lead us to the conclusion that nuclear generating capacity will be 33 percent of total capacity (excluding pumped storage) and will provide 43.6 percent of the raw energy required for electric generation in 1985. There are many "ifs" involved in developing these predictions, but each "if" seems to be a logical supposition.

Hydro energy sources will probably be the least affected by nuclear development, but the importance of hydro will continue to decrease for the reasons cited earlier. Hydro provided 18.4 percent of electric energy requirements in 1965. We predict that hydro will account for only 12.4 percent of the total electric energy generated in 1975 and 8.6 percent in 1985. Even so, hydro generation will amount to 320 billion kWh in 1985 as compared with 193 billion kWh in 1965. We estimate that more than 50 percent of the 20-year increase in conventional hydro generation will occur in the Pacific and Mountain states.

The electric energy not produced from nuclear or hydro sources must be developed from fossil fuels. Gas does not generally compete with coal as a base load or normal fuel. Each is the normal fuel in different parts of the country as a function of generating plant location to fuel reserves. Coal is the predominant fuel in the Northeast, and gas in the South and Southwest. Oil does not normally compete with gas but does compete with coal in the coastal areas. Thus while fossil fuels in the aggregate will provide a lesser percentage of total generation because of nuclear gains, the ratio of gas to coal to oil use is not expected to vary appreciably from the present-day pattern, in which 66 percent of the fossil-fueled generation is by coal, 26 percent by gas, and 8 percent by oil. Because of the time delay before nuclear generation becomes economic in the South, we expect that by 1985 the fossil-fueled generation will be about 28 percent by gas, with coal still accounting for 66 percent, and oil providing about 6 percent of the electric energy.

These then are the processes and considerations used in arriving at our predictions of installed generating capacity and electric energy generation by energy sources. Analyses of current trends indicate to us that these are the best predictions that can be made today, and predictions are necessary if we are to plan for the energy resources required for electric generation in the future.

Regional outlook

Although the national picture with respect to installed generating capacity, electric energy, and raw energy sources is of overall interest, each electric utility is primarily concerned with the requirements for raw energy resources in its particular area. Figure 9 illustrates the geographic area encompassed by each of the nine continental U.S. Census Divisions. Division J, which covers Alaska and Hawaii, is not shown. In the following discussion I have included energy requirements for Alaska and Hawaii in the Pacific Division (Division I) because they account for less than 2 percent of the Division I energy requirements and less than 0.25 percent of total U.S. requirements.

Table IV illustrates the historical and projected electric generation in each of the nine continental U.S. Census Divisions. The 1955 and 1965 figures are of record. The 1975 and 1985 figures are our projections. In making these projections we have assumed that historical trends will continue. Thus the electric generation, and hence the raw energy requirements for electric generation, will continue to decline as a percentage of the U.S. total in the entire area east of the Mississippi River except for Kentucky, Tennessee, Alabama, and Mississippi. The electric energy generation in the entire country west of the Mississippi River plus the four states named east of the Mississippi will continue to increase as a percentage of U.S. total. This is the result of the gradual movement of population and industrial activity toward the West, a trend that has been evident for the past 175 years and that has become particularly pronounced in the past two decades.

Having estimated the electric energy requirements by U.S. Census Divisions we then estimated the raw energy sources that will provide that generation. Table V summarizes the results of our studies and estimates. This chart shows the energy sources for electric generation in each of the nine Census Divisions. Although the electric energy generated in the future in each of the Census Divisions is expected to follow the historical trend, the energy resources required for the generation in each region are expected to show very significant deviations from past trends—primarily as a result of the impact of nuclear energy.

The magnitude of these changes is perhaps more clearly illustrated by Table VI, which shows the percentage of electric energy that has been and will be generated by each source in each of the Census Divisions. The electric utilities have one primary interest and that is the furnishing of electric power and energy in the amounts required and when required, with the highest practical reliability of service, and at the lowest practical cost. The changing pattern of fossil versus nuclear energy sources will be the result of economic comparisons made between fossil and nuclear generation.

IV. Total generation by electric utility industry, billion kWh

	U.S. Census Divisions	1955	1965	1975	1985
A	New England	23	40	75	130
B	Middle Atlantic	86	157	290	500
C	East North Central	127	216	350	560
D	West North Central	30	63	130	270
E	South Atlantic	71	154	330	670
F	East South Central	66	112	205	350
G	West South Central	41	101	230	480
H	Mountain	24	50	95	160
I	Pacific (including overseas)	79	162	315	580
	Total U.S.A.	547	1055	2020	3700

Table VII provides the basic reason for the increasing dependence on nuclear sources. This chart summarizes the average price paid by the electric utilities for coal, oil, and gas in each of the Census Divisions in 1965. I mentioned earlier (Table III) that the average U.S. delivered fuel price to electric utilities in 1965 was 25.2¢/MBtu and that this figure was between the minimum and maximum fuel prices that we estimate are required to break even with nuclear costs today for large units. Table VII shows that the 25.2¢/MBtu 1965 average fuel price is the result of fuel prices ranging from 33.8¢/MBtu in New England, which has no indigenous fuel resources but must import all fuel, down to 19.3¢/MBtu in the East South Central Division, where there is very substantial coal production and thus only nominal transportation to the plant sites is required.

From comparisons of Tables VI and VII it is evident that our predictions of nuclear energy are related to the average 1965 fuel prices and to our belief that coal prices will continue to decline, that oil prices will decline but maintain their present relationship to coal along the coast, that gas prices will increase, and that hydro developments will be limited. If we relate nuclear generation to total generation, excluding hydro, these relationships become more evident, as shown in Table VIII.

Thus the higher the average fossil fuel price, the greater will be the impact of nuclear energy and the earlier will nuclear energy become a major source for electric generation.

The pattern of 1985 nuclear generation as a percentage of total generation in each region decreasing as a function of decreasing average fuel price is consistent except for Divisions F and G. Here we predict that nuclear generation will in 1985 provide a greater percentage in Division F than in G, because Division F is today predominantly a coal-burning area whereas Division G is predominantly gas. The air pollution regulations that will probably be enacted will in our opinion have the effect of increasing the equivalent cost of coal, thereby advancing the time when nuclear energy will be the economical source in Division F.

By 1985 nuclear energy will provide 43.6 percent of total U.S. electric energy (Fig. 6) and regionally it will range from 72.3 percent of total generation in New England to 23.4 percent in the states of Texas, Oklahoma, Louisiana, and Arkansas.

V. Regional electric utility generation by raw energy sources, billion kWh

Census Division	1955	1965	1975	1985
A New England				
Coal	10.5	23.0	20.0	20.0
Nuclear	0.0	1.0	40.0	94.0
Oil	6.9	11.0	10.0	10.0
Hydro	4.6	3.7	4.0	5.0
Gas	0.7	1.0	1.0	1.0
B Middle Atlantic				
Coal	65.5	105.0	110.0	120.0
Nuclear	0.0	1.0	108.0	296.0
Oil	6.8	21.0	35.0	40.0
Hydro	9.8	20.6	26.0	32.0
Gas	4.0	8.9	11.0	12.0
C East North Central				
Coal	117.2	205.0	269.0	300.0
Nuclear	0.0	1.2	69.0	246.0
Oil	0.7	0.5	1.0	1.0
Hydro	3.4	3.7	4.0	5.0
Gas	5.3	6.2	7.0	8.0
D West North Central				
Coal	13.0	26.6	59.0	100.0
Nuclear	0.0	0.1	22.0	116.0
Oil	1.2	0.6	1.0	1.0
Hydro	3.4	10.0	14.0	16.0
Gas	12.8	25.5	34.0	37.0
E South Atlantic				
Coal	48.3	111.4	190.0	280.0
Nuclear	0.0	0.1	76.0	314.0
Oil	9.0	17.4	30.0	35.0
Hydro	8.9	14.5	19.0	23.0
Gas	5.2	10.5	15.0	18.0
F East South Central				
Coal	46.1	86.7	150.0	180.0
Nuclear	0.0	0.0	25.0	131.0
Oil	0.0	0.0	0.0	0.0
Hydro	15.5	18.3	20.0	25.0
Gas	4.9	7.4	10.0	14.0
G West South Central				
Coal	0.0	0.0	19.0	65.0
Nuclear	0.0	0.0	8.0	112.0
Oil	0.2	0.1	0.0	0.0
Hydro	1.9	2.6	3.0	5.0
Gas	38.8	98.3	200.0	298.0
H Mountain				
Coal	1.8	13.3	35.0	50.0
Nuclear	0.0	0.0	8.0	50.0
Oil	0.6	1.0	2.0	2.0
Hydro	14.4	23.8	31.0	40.0
Gas	7.2	11.9	19.0	18.0
I Pacific (including overseas)				
Coal	0.0	0.0	13.0	40.0
Nuclear	0.0	0.3	74.0	256.0
Oil	11.7	13.3	16.0	21.0
Hydro	51.1	96.1	129.0	169.0
Gas	16.4	52.3	83.0	94.0

VI. Regional electric utility generation by raw energy sources, percent

Census Division	1955	1965	1975	1985
A New England				
Coal	46.2	57.8	26.6	15.4
Nuclear	0.0	2.5	53.5	72.3
Oil	30.4	27.8	13.3	7.7
Hydro	20.3	9.4	5.3	3.8
Gas	3.1	2.5	1.3	0.8
B Middle Atlantic				
Coal	76.1	67.1	37.9	24.0
Nuclear	0.0	0.6	37.2	59.2
Oil	7.9	13.3	12.1	8.0
Hydro	11.4	13.3	9.0	6.4
Gas	4.6	5.7	3.8	2.4
C East North Central				
Coal	92.5	94.8	76.8	53.3
Nuclear	0.0	0.5	19.8	43.8
Oil	0.6	0.2	0.3	0.2
Hydro	2.7	1.7	1.1	1.1
Gas	4.2	2.8	2.0	1.6
D West North Central				
Coal	42.6	42.5	45.3	37.0
Nuclear	0.0	0.1	16.9	43.1
Oil	4.0	0.9	0.8	0.3
Hydro	11.2	16.0	10.8	5.9
Gas	42.2	40.5	26.2	13.7
E South Atlantic				
Coal	67.6	71.3	57.7	41.8
Nuclear	0.0	0.0	23.0	46.9
Oil	12.6	11.3	9.1	5.2
Hydro	12.5	10.6	5.7	3.4
Gas	7.3	6.8	3.5	2.7
F East South Central				
Coal	69.3	77.1	73.2	51.5
Nuclear	0.0	0.0	12.2	37.4
Oil	0.0	0.0	0.0	0.0
Hydro	23.3	16.3	9.7	7.1
Gas	7.4	6.6	4.9	4.0
G West South Central				
Coal	0.0	0.0	8.3	13.6
Nuclear	0.0	0.0	3.4	23.4
Oil	0.5	0.0	0.0	0.0
Hydro	4.5	2.6	1.3	1.0
Gas	95.0	97.4	87.0	62.0
H Mountain				
Coal	7.5	26.6	36.9	31.2
Nuclear	0.0	0.0	8.4	31.3
Oil	2.5	2.0	2.1	1.3
Hydro	60.0	47.6	32.6	25.0
Gas	30.0	23.8	20.0	11.2
I Pacific (including overseas)				
Coal	0.0	0.0	4.1	6.9
Nuclear	0.0	0.2	23.4	44.1
Oil	14.8	8.2	5.1	3.6
Hydro	64.5	59.2	41.0	29.2
Gas	20.7	32.4	26.4	16.2

VII. Regional fossil fuel costs for electric energy generation, 1965

Percent Total Fossil Btu			Average Fuel Cost, cents/MBtu			Weighted Average Fossil Fuel Cost, cents/MBtu
Coal	Oil	Gas	Coal	Oil	Gas	
A New England						
61	36	3	32.4	34.4	34.2	33.8
B Middle Atlantic						
77	16	7	25.4	32.3	33.8	27.7
C East North Central						
97	0	3	23.7	66.2	25.9	23.3
D West North Central						
51	1	48	25.6	50.8	24.2	25.5
E South Atlantic						
80	12	8	24.8	33.7	32.3	25.7
F East South Central						
92	0	8	18.4	62.8	23.8	19.3
G West South Central						
0	0	100	—	—	19.8	19.8
H Mountain						
49	4	47	19.0	26.2	27.1	23.3
I Pacific						
0	19	81	—	32.0	31.4	31.5

VIII. Comparisons of nuclear generation with total generation, excluding hydroelectric

Census Division	Nuclear Percent of Total Generation, 1985	Highest to Lowest Nuclear Rank, 1985	Highest to Lowest 1965 Fuel Cost
A	75.2	1	1
I	63.5	2	2
B	63.3	3	3
E	48.5	4	4
D	45.7	5	5
C	44.4	6	6
H	42.8	7	7
F	40.3	8	9
G	23.6	9	8

The rapid increase in electric generation by nuclear means will affect every other energy source in every region without exception. In every region all fossil fuels and hydro will provide a smaller percentage of the regional electric generation in 1985 than they did in 1965.

Figure 7 shows that on a national basis the consumption of all forms of raw energy for electric generation will increase substantially between 1965 and 1985. However, this will not be true for all fuels in all regions. Table IX, which is derived from the data in Tables IV and V, shows the raw energy requirements for electric generation by energy sources in each of the regions for 1965 and 1985. For convenience of reference all of the energy sources are given in equivalent tons of coal, as in Fig. 7.

IX. Raw energy requirements for electric energy generation, millions tons of coal equivalent

	1965	1985		1965	1985
A New England			**F East South Central**		
Coal	9.9	7.6	Coal	37.2	68.2
Nuclear	0.5	35.7	Nuclear	0.0	49.6
Oil	5.3	3.8	Oil	0.0	0.0
Hydro	1.6	1.9	Hydro	7.9	9.5
Gas	0.4	0.4	Gas	3.2	5.3
B Middle Atlantic			**G West South Central**		
Coal	45.0	45.5	Coal	0.0	24.7
Nuclear	0.5	112.0	Nuclear	0.0	42.5
Oil	10.1	15.1	Oil	0.1	0.0
Hydro	8.8	12.1	Hydro	1.1	1.9
Gas	3.9	4.5	Gas	43.3	113.1
C East North Central			**H Mountain**		
Coal	88.0	114.0	Coal	5.8	19.0
Nuclear	0.6	93.4	Nuclear	0.0	19.0
Oil	0.2	0.4	Oil	0.5	0.8
Hydro	1.6	1.9	Hydro	10.3	15.2
Gas	2.7	3.0	Gas	5.2	6.8
D West North Central			**I Pacific (including overseas)**		
Coal	11.4	37.0	Coal	0.0	15.2
Nuclear	0.0	44.0	Nuclear	0.2	97.2
Oil	0.3	0.4	Oil	5.4	8.0
Hydro	4.3	6.1	Hydro	41.4	64.0
Gas	11.3	14.0	Gas	23.0	35.7
E South Atlantic			**National total**		
Coal	47.7	106.0	Coal	244.9	438.0
Nuclear	0.0	119.0	Nuclear	1.8	612.4
Oil	8.4	13.2	Oil	30.3	41.7
Hydro	6.2	8.7	Hydro	83.2	121.3
Gas	4.4	6.8	Gas	87.4	189.6
				457.6	1403.0

In all regions other than New England the consumption of fossil fuels will continue to increase, but the rate of increase will be less than in the past because of increases in nuclear generation. In New England, where all fossil fuels must be imported, nuclear energy will actually decrease the consumption of fossil fuels in the next 20 years.

Summary

I have attempted to predict the degree to which alternative energy sources will be used in the foreseeable future for electric energy generation. I have based these predictions on recent trends in the industry, a review of fuel reserves, and consideration of the uses of fuels for other than electric energy generation.

We can expect that sellers of each type of raw energy source will attempt to keep as large a share of the available market as possible. Those in the utility industry devoting their efforts to energy resources planning will naturally take advantage of whatever opportunities are offered; however, unless there are technological developments not now anticipated we believe that the long-range energy resource picture will be about as I have described.

Revised text of a paper presented at the American Power Conference, Chicago, Ill., April 23–25, 1968. The paper will also appear in the *Proceedings* of that conference.

Time synchronization from Loran-C

The capabilities of Loran-C for time synchronization are opening new vistas relating to the conception and implementation of communications and measurement systems

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Loran-C navigational transmissions, at a frequency of 100 kHz, can be used to provide clock synchronization over long distances to accuracies within ± 1 μs. Results to date represent improvements as great as three magnitudes over other operational long-range radio systems. This article discusses the timing capabilities of Loran-C and illustrates the techniques that are used for the derivation of time and frequency.

Loran-C, a navigation system, was first recognized as a means of microsecond-time dissemination by the National Bureau of Standards.[1,2] The U.S. Naval Observatory (USNO) has conducted Loran-C experiments[3-5] since 1961, and is currently engaged in a cooperative program with the U.S. Coast Guard to provide time services with Loran-C over much of the world.

At the present time, synchronization to within a microsecond of the USNO master clock may be accomplished over much of the continental United States, Puerto Rico, the Hawaiian Islands, and the Northwest Pacific (including Japan). In August 1968, time services will be extended to additional Loran-C networks providing coverage over the North Atlantic and Northwestern Europe.

I. Basic group repetition rates

Identification	Pulse Groups per Second
H	33 1/3
L	25
S	20
SH	16 2/3
SL	12 1/2
SS	10

II. Loran-C group periods for basic and specific rates, microseconds

Specific Rate	Basic Rate SS	SL	SH	S	L	H
0	100 000	80 000	60 000	50 000	40 000	30 000
1	99 900	79 900	59 900	49 900	39 900	29 900
2	99 800	79 800	59 800	49 800	39 800	29 800
3	99 700	79 700	59 700	49 700	39 700	29 700
4	99 600	79 600	59 600	49 600	39 600	29 600
5	99 500	79 500	59 500	49 500	39 500	29 500
6	99 400	79 400	59 400	49 400	39 400	29 400
7	99 300	79 300	59 300	49 300	39 300	29 300

The loran system

Loran (LOng RAnge Navigation)[6] was developed during World War II, at the M.I.T. Radiation Laboratory, to provide ships and aircraft with a means of precise navigation. Basically, a loran chain consists of a master and two or more slave stations. A pulse transmitted from the master station is received via ground wave by a slave station—which, in turn, transmits its pulse at a fixed time later. This fixed time, known as the coding delay, is kept constant by monitor stations that "steer" the chain. Its value is selected to ensure that signals in a chain will always arrive at a receiver in sequence, and not overlap. Coding delay is not to be confused with emission delay, which will be discussed later.

The time difference between reception of a master-slave pulse pair determines a hyperbolic line; the intersection of two such lines gives position. Standard loran, also known as Loran-A, operates in the 2-MHz band. Each station transmits pulses of 45-μs duration, which occupy a bandwidth of 75 kHz. Envelope match is the basis for time-difference measurement. This is normally accomplished by causing the master and slave envelopes

FIGURE 1. Active Loran-C stations.

to be superimposed by adjustment of calibrated delay controls while visually monitoring the waveforms on an oscilloscope.

Loran-C

Loran-C[7,8] was developed to extend loran coverage with fewer stations. Use of a 100-kHz carrier frequency allows greater range due to lower ground-wave attenuation and, consequently, permits use of longer station-to-station baselines. High precision is obtained by both envelope matching of the pulse and phase matching of the cycles within the pulse. The pulse length is approximately 300 μs, and the channel frequency allocation is from 90 to 110 kHz. All Loran-C stations operate at 100 kHz. Adjacent chains employ different repetition rates for identification. The particular rates are selected to be commensurate with the baselines and to provide minimum cross-rate interference. Basic pulse group repetition rates allocated for Loran-C appear in Table I. Coupled with these are offsets in 100-μs period increments that yield a group of so-called specific rates. A complete listing of allocated Loran-C repetition periods is shown in Table II. A Loran-C station may be shared by adjacent chains, in which case the station is pulsed at two rates—one of them taking precedence during instances of overlap.

At the present time, 30 Loran-C stations are in operation. The chains are composed of two triplets, three groups of four, and three of five stations each, as shown in Fig. 1. Table III lists the locations of the stations, the repetition rates, and other pertinent information. Loran-C signals are usable for timing to a microsecond on ground-wave reception to a distance of about 1500 km landward, or 3000 km seaward, and on sky-wave reception at reduced accuracy to about 10 000 km.

The high accuracies obtained with Loran-C result from the ability to separate the ground wave from the sky wave at the receiver and to identify particular ground-wave cycles within the pulse. Loran-C transmitters and their antennas are specially designed to produce a signal

III. Loran-C station data

Chain	Rate	Period, μs	Master[a]	Slaves[a,b] W	X	Y	Z
East Coast	SS-0	100 000	Cape Fear, N.C. ("T" slave sometimes broadcasts from Wildwood, N.J., at ED 84028.7 μs)	Jupiter, Fla. 13 695.5	Cape Race, Newfoundland (4 MW) 36 389.6	Nantucket Island, Mass. 52 542.5	Dana, Ind. 68 564.2
Central Pacific (Hawaiian)	SH-4	59 600	Johnston Island		Upolo Point, Hawaii 15 971.8	Kure Island, Hawaii 35 252.4	
Mediterranean	SL-4	79 600	Simeri Chichi (Catanzaro), Italy		Matratin, Libya 14 107.6	Targabarun, Turkey 32 273.3	Estartit, Spain 50 999.7
North Atlantic	SL-7	79 300	Angissoq, Greenland (500 kW)	Sandur, Iceland (4 MW) 15 068.2	Ejde, Faeroe Islands 27 803.9		Cape Race, Newfoundland (4 MW) 48 212.3
Northern Pacific (Alaskan)	SL-2	79 800	St. Paul, Pribiloff Islands		Sitkinak, Alaska 14 284.4	Attu, Aleutian Islands 31 875.3	Port Clarence, Alaska (1850 kW) 53 069.1
Norwegian Sea	SL-3	79 700	Ejde, Faeroe Islands	Sylt, Germany 30 065.6	Bo, Norway 15 048.1	Sandur, Iceland 48 944.5	Jan Mayen, Norway 63 216.3
Northwest Pacific	SS-3	99 700	Iwo Jima (4 MW)	Marcus Island (4 MW) 15 283.3	Hokkaido, Japan 36 685.2	Gesashi, Okinawa 59 463.0	Yap Island (4 MW) 80 746.5
Southeast Asia	S-3	49 700	Sattahip, Thailand		Lampang, Thailand 13 182.8 (computed)	Con Son Island, South Vietnam 29 522.1 (computed)	

[a] Power 250–400 kW, except where noted.
[b] Emission delay given with reference to master. Information current but subject to change.

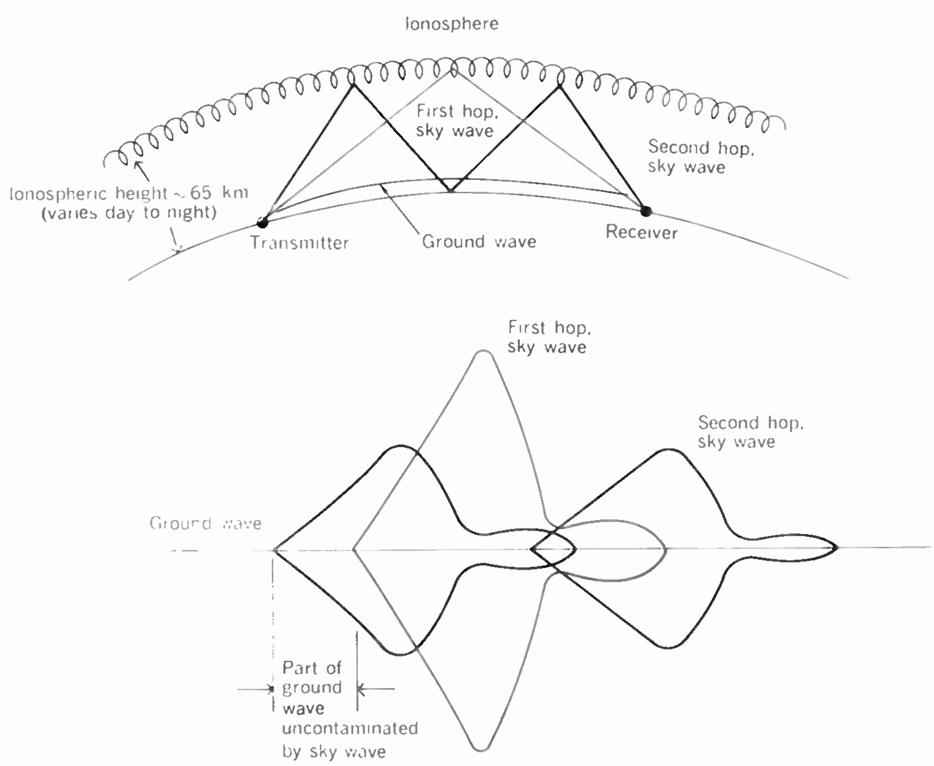


FIGURE 2. Typical ground-wave/sky-wave pattern. As range increases, the sky wave will arrive closer to the beginning of the ground wave. Because of the curvature of the earth, the minimum delay at maximum range reaches an asymptote of about 30 μs. The composite of all the waves may vary in envelope according to the current ionospheric conditions (see Fig. 6).

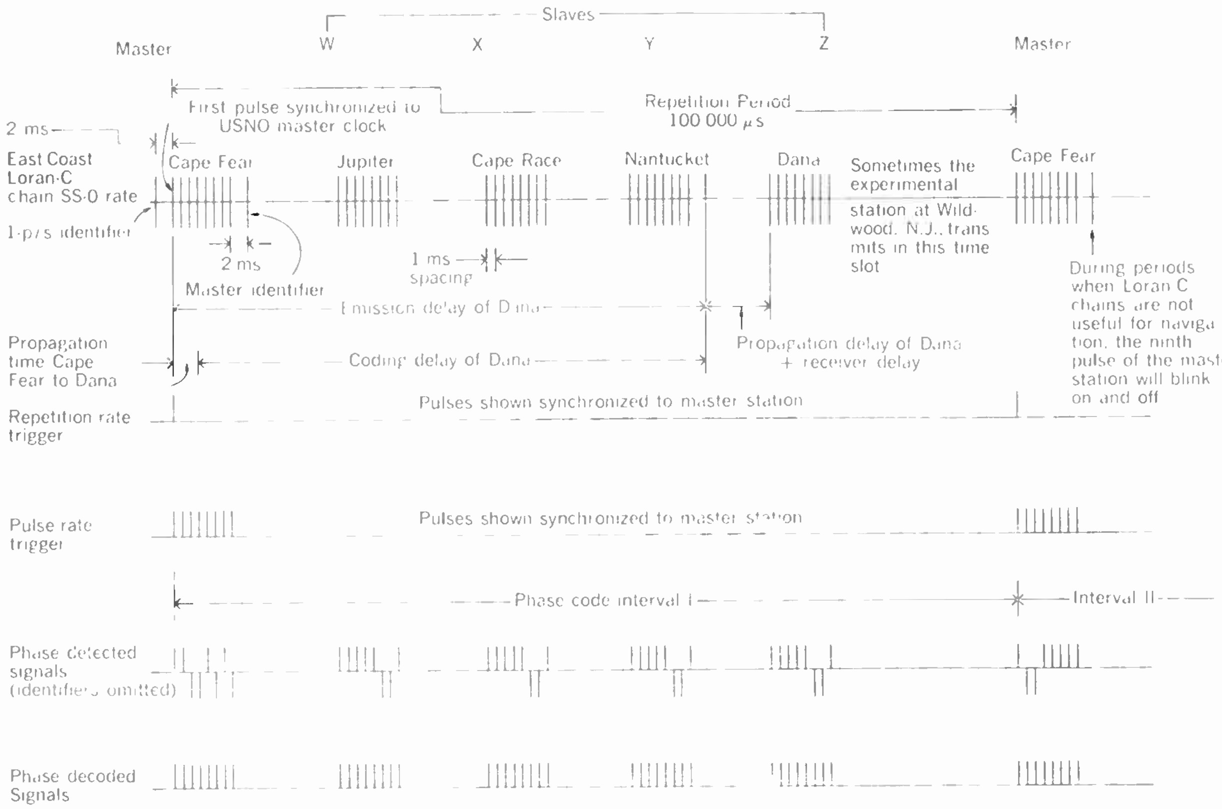
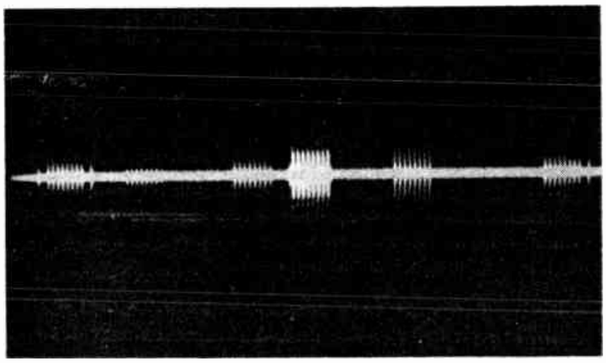


FIGURE 3. Loran-C format and waveforms.

FIGURE 4. Nighttime oscillogram of East Coast Loran-C chain, as taken from Boston. From left to right are the master station at Cape Fear, N.C., and the slaves at Jupiter, Fla.; Cape Race, Nfld.; Nantucket, Mass.; and Dana, Ind. Cape Fear is shown twice to illustrate the presence of the 1-p/s identifier occurring only at the left, positioned 2 ms prior to the first pulse of the master group.



that rises rapidly, achieving an amplitude of 50 percent peak within the first three cycles (30 μs) of the transmitted pulse.

Figure 2 illustrates a ground-wave/sky-wave pattern typically encountered with Loran-C pulses. It is seen that as range increases, the first-hop sky wave will arrive at the receiver progressively closer in time to the ground wave. At 1500 km landward, or 3000 km seaward, the delay is in excess of 30 μs[7] and depends upon the time of day, latitude, and ground conductivity. In addition, the sky wave is often many times stronger in amplitude, especially at night. For a precise measurement, only that

IV. Loran-C phase code

	Master								Slave							
Pulse	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
Interval I	+	+	−	−	+	−	+	−	+	+	+	+	+	−	−	+
Interval II	+	−	−	+	+	+	+	+	+	−	+	−	+	+	−	−

+ represents 0° phase; − represents 180° phase. Intervals I and II refer to alternate repetition periods. Slaves always transmit the same interval as the master during any repetition period. Reference to Fig. 3 will help in understanding the phase-code format.

part of the ground wave is used that is not contaminated by the sky-wave signal. Because of this, Loran-C stations transmit a burst of eight pulses spaced 1 ms apart during each repetition period to maximize the uncontaminated ground-wave information at the receiver. The master station transmits a ninth pulse, 2 ms after the eighth, for identification. Figure 3 is a representation of a Loran-C format using the East Coast chain as the model. Additional waveforms are shown to provide an aid to the understanding of Loran-C techniques. Figure 4 shows an oscillogram of the East Coast chain as received in Boston.

It is not unusual, especially at night, for multihop sky waves to arrive at the receiver delayed a millisecond from the ground wave, thereby causing interference to the second through eighth pulses. To minimize this contamination and to reduce the effects of coherent noise, the Loran-C system employs phase coding of alternate pulses and groups. Table IV summarizes the phase code in use on all the Loran-C chains. An examination of Fig. 3 in conjunction with Table IV will help to illustrate the phase-code format. Figure 5 is an oscillogram of a Loran-C signal showing the eight pulses superimposed and the same pulses decoded.

A Loran-C period is initiated by the transmission from the master station. At certain times later, the slaves transmit their bursts of eight pulses. These times, called emission delays, are known to about 0.1 μs.* The emission delay is equal to the propagation time from the master to a slave, plus the coding delay, as shown in Fig. 3. At the end of the repetition period, a new cycle begins with the transmission of the master station. It is planned that master stations transmit a 1-pulse-per-second identifier. On the East Coast chain, the Cape Fear station transmits a pulse 2 ms previous to the first pulse of the groups synchronized to the USNO seconds' tick.

Ground-wave arrival time is consistent to within 0.1 μs. Beyond ground-wave range, both navigation and timing can be achieved, but with reduced accuracy. Sky-wave consistency can be of the order of a few microseconds when measured according to a prescribed procedure.[9,10] Using sky waves most effectively involves selecting the portion of the sky-wave pulse that is least contaminated by ground-wave or other sky-wave modes. Reference to Fig. 6 will show that this point may not be at the beginning of the pulse.

* The values of the emission delays given in Table III are derived from the data given on Loran-C navigation charts, published by the U.S. Naval Oceanographic Office. Values for the Southeast Asia chain, which are preliminary, were received by the author in a personal communication with the U.S. Coast Guard.

Time derivation

Derivation of time for Loran-C signals involves the precise determination of the time of arrival of the signals at the receiver. From Fig. 5, it is seen that the Loran-C pulse is composed of cycles of the 100-kHz carrier. Time synchronization depends on identifying a particular cycle and then comparing a crossover within the cycle with the reference clock. In order to facilitate cycle identification, the leading edge of the envelope is carefully controlled at the transmitter to conform to the expression

$$f(t) = (kt)^2 e^{-2(kt-1)} \qquad \text{where } k = \frac{1}{72.5 \times 10^{-6}}$$

so that the relative amplitudes of the first few cycles are identical for every transmitter. The envelope reaches a maximum at the positive peak of the seventh cycle, at 72.5 μs (see Fig. 5).

There have been numerous techniques developed for automatic cycle identification. One that we have found to be particularly powerful involves sampling of the relative amplitudes of the first six half-cycles of the pulse (that portion free from sky-wave contamination), and applying these to a matched filter circuit, which will indicate that the cycles selected are, in fact, the ones of interest. The matched filter presents a neutral indication when sampling the proper sequence, and yields negative or positive output readings for early or late sampling, respectively.

One might question the reason for employing special devices such as matched filters for cycle selection because the cycles forming the pulse shown in Fig. 5 are well defined, and one may visually count cycles back from peak, or up from the beginning. Figure 5 shows a simulated pulse uncontaminated by sky waves; however,

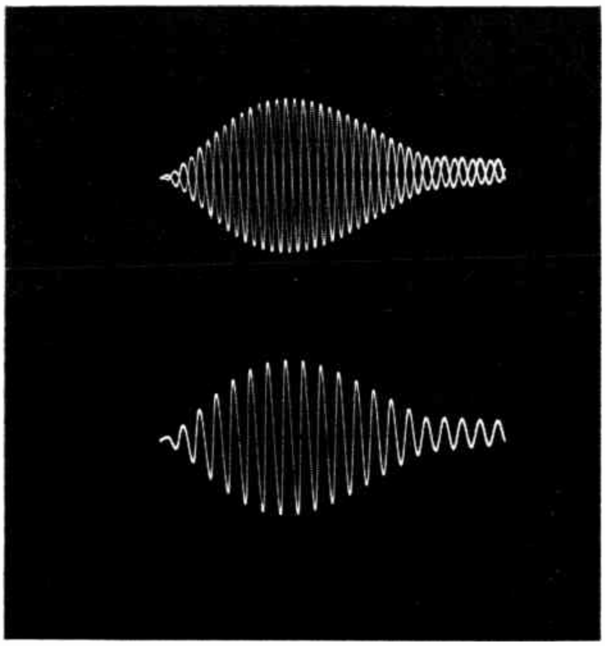


FIGURE 5. Oscillogram of a Loran-C signal showing eight pulses overlaid (top) and the same pulses decoded (bottom). (From Loran-C simulator.)

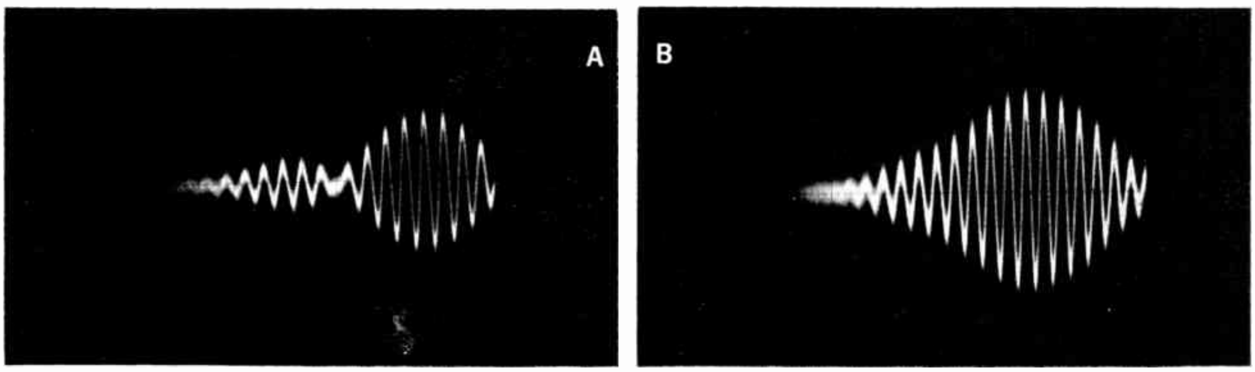


FIGURE 6. Oscillograms of a Loran-C signal, illustrating sky-wave effects. A—Sky wave arriving in phase opposition to the ground-wave component. B—In-phase arrival. It is evident that visual cycle selection is complicated by the sky-wave signal. Oscillograms are of the Cape Fear signal as received in Boston at night.

more typical waveforms are illustrated in Fig. 6. It is evident that selection of the ground-wave peak can be uncertain. Counting from the beginning of the pulse requires that the beginning be well defined. This will be discussed in the next section. In general, the precision of clock synchronization using Loran-C by visual cycle selection is about ±20 μs.

Cycle identification

The ability to derive time to accuracies of better than about ±20 μs when Loran-C pulses are employed depends upon the operator's ability to properly identify a particular cycle. Much has been said and written regarding the cycle-selection problem although little information is available that fully describes the proper technique required.

Historically, Loran-C measurements have been made by observing what appears to be the first three cycles of the pulse, which are assumed to be free of sky-wave contamination. However, when a band-limited receiver is used, observation of these three cycles as being the first three cycles will happen only until the gain of the receiver is increased, or the input level increased; earlier cycles will then be observed, adding complications to this cycle-selection problem.

These earlier cycles, or "precursors," are the low-level output of the receiver that commences upon application of the input pulse. After a delay of about 25 μs, there occurs a sharp upswing of the output envelope function conforming to the pulse output that is normally used for measurement purposes. Consequently, sampling of the received Loran-C pulse during the first three cycles must be redefined as "the first three cycles of significance," which are those occurring approximately 25 μs following the application of the pulse to the receiver. Cycle-selector circuits should be designed to match to these first three cycles of significance and, consequently, will indicate that the receiver is correctly positioned when set for these cycles. This technique is valid as long as the sky-wave amplitude at the receiver is somewhat less than 40 dB in excess of the ground-wave amplitude—at which point the precursor from the sky-wave signal will be of the same order of magnitude as the sampled portion of the ground-wave signal. The receivers used for Loran-C operation should be designed for the minimum precursor for a particular bandwidth.

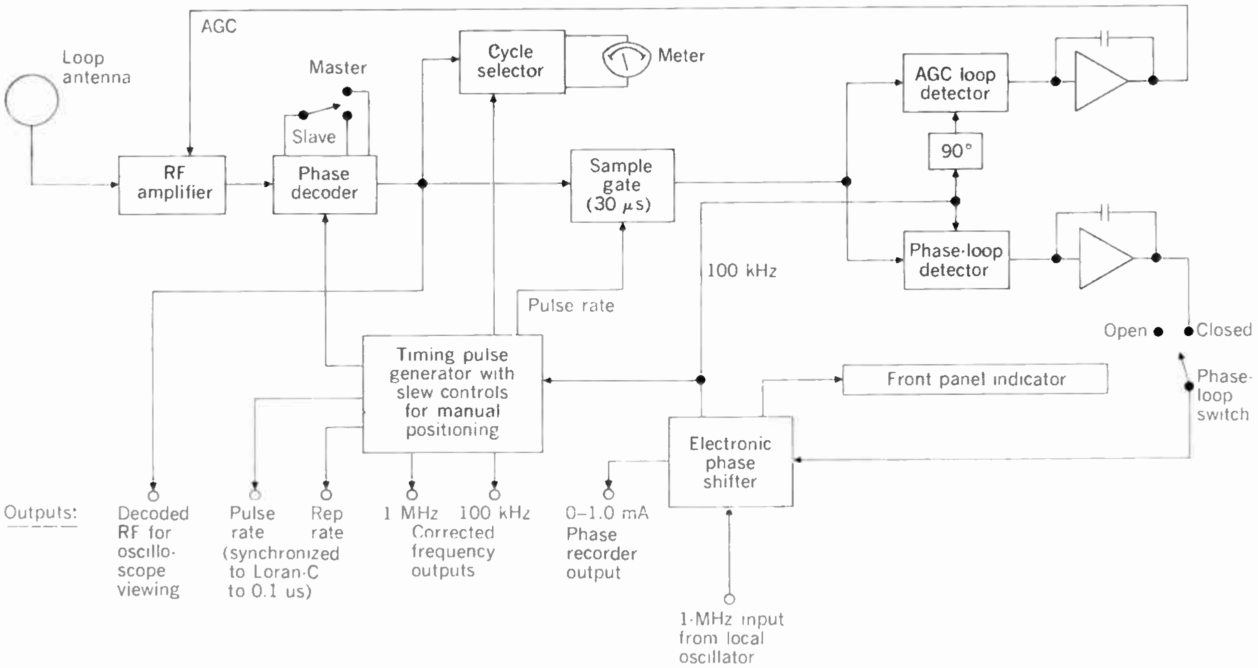
It is important that the delay through the receiver be known precisely. Normally, this will be specified by the manufacturer to within a microsecond. For absolute measurements requiring greater precision, it is recommended that the exact delay be determined by use of a Loran-C simulator.

Timing receivers

There are three basic types of receiving equipment used for frequency and time synchronization to Loran-C. They are automatic receivers, phase-tracking receivers, and visual receivers. Each will be discussed and comments made about their relative application. The configurations shown are representative of the general complexity required in each case. Various commercial units differ in detail.

The automatic receiver shown in Fig. 7 takes its reference input from a local oscillator at 1 MHz. Internal digital circuitry is switched to select the repetition rate of the station to be observed and to provide the proper master- or slave-phase decoding function. An oscilloscope, which is required for initial adjustment, takes its vertical input from the decoded RF output and its trigger from the pulse rate output. While monitoring the oscilloscope, the trigger pulses are slewed to coincide with the beginning of the Loran-C pulse. After setting the sample

FIGURE 7. Simplified block diagram of an automatic receiver. The oscilloscope used for initial adjustment normally takes its vertical input from the decoded RF output and its trigger from the pulse-rate output.



gate, the phase-tracking servo loop is activated. The receiver will automatically adjust the timing of this gate by means of the electronic phase shifter to bracket the three cycles to within 0.1 μs. When the phase loop has stabilized, the cycles that have been selected are sampled by the cycle selector, and output is provided to a front panel meter to indicate whether the proper cycles of the pulse have been selected and, if not, whether the sample gate should be advanced or retarded in 10-μs (one-cycle) steps.

An automatic receiver will indicate when the proper cycle has been selected and will develop a repetition-rate pulse that is synchronized to the time of arrival of the Loran-C signal to within 0.1 μs, after receiver delay correction. A digital counter, calibrated in tenths of microseconds, indicates the phase-error accumulation between the local oscillator and the Loran-C signal; terminals are normally provided for connection to a pen recorder for recording oscillator drift on a continuous basis. "Corrected" frequency outputs, usually available at 1 MHz and 100 kHz, are locked to the phase of the Loran-C signal. This "corrected" frequency possesses the long-term stability of the Loran-C station and can be used to drive clocks directly or to provide steering to local oscillators.

A phase-tracking receiver operates with respect to Loran-C in a similar fashion as a standard very-low-frequency phase comparator to VLF signals. Its phase record of ground-wave signals does not possess diurnal shift, and consequently comparisons can be made faster and with greater precision. An oscilloscope must be used as described previously to position the sample gate. The unit is similar to an automatic receiver in most respects except that it does not contain cycle-selection circuitry. Time reference may be obtained from a Loran-C phase-tracking receiver in the same way as will be described for the visual receiver.

A visual receiver is basically a 100-kHz RF amplifier designed to provide amplification of the Loran-C signal with a maximum degree of fidelity, while at the same time rejecting out-of-band noise and interference. In general, it is used with an external repetition-rate generator whose output pulses trigger an oscilloscope. These pulses must be capable of being moved in the time domain (slewed) so that the Loran-C signal can be positioned appropriately. With simple repetition rates such as those used with the East Coast chain, a 1-p/s (pulse-per-second) trigger may be used to view the Loran-C signal. With other chains it is necessary to use somewhat more sophisticated techniques, which will be discussed later.

Use of both automatic and phase-tracking receivers is most effective within ground-wave range of the Loran-C station. Beyond the ground-wave range, phase-tracking and cycle-selection circuitry become less useful because of ionospheric variations, and more reliance is made on visual techniques for positioning the local clock pulses with respect to the Loran-C station. Both whip and loop antennas are commonly used with Loran-C. For timing purposes (fixed station), a loop is more convenient in that it may be electrostatically shielded and positioned to null local noise centers.

Loran-C time services

With the cooperation of the U.S. Coast Guard, the Naval Observatory has taken steps to synchronize Loran-C transmissions to the observatory's master clock. Cesium-beam oscillators are being installed at the Loran-C master stations to provide a basic stability to the system of the order of a microsecond per day, which is further improved with steering. Since the master clock is on UTC (Universal Time, Coordinated), all frequencies derived from the Loran-C transmissions will be on this scale, which for 1968 is offset by −300 parts in 10^{10} from Atomic Standard Frequency.

Transmissions of Loran-C master stations are steered by the observatory to be synchronous with the UTC second marker pulse, with reference to an epoch. The reference epoch has been established as 0000 hours UT, January 1, 1958, at which time it is assumed that the first pulse of the master station group of each Loran-C chain so synchronized was transmitted. Times of coincidence (TOCs) between this pulse and the UTC second will occur periodically, at which times clocks can be set to the Loran-C transmissions in a straightforward manner. TOC tables for the various Loran-C chains are published by the Naval Observatory. Values of T for currently operating chains, and their synchronization status, are presented in Table V.

Monitor stations have been set up by the observatory in the Far East and Hawaii to provide the steering information. Stations will be added in other areas in the future. Reference to the master clock is made by a combination of traveling-clock, VLF phase-comparison, and satellite techniques. Because of the nature of the Loran-C system, slave transmissions are automatically synchronized to master transmissions to about 0.1 μs and, consequently, may also be used for time and frequency reference.

In addition to the standard navigational transmissions, a number of the Loran-C master stations transmit 1-p/s identifiers synchronized to UTC. They are transmitted without phase code (+ polarity) and on time, except on the East Coast chain, where the Cape Fear 1-p/s identifier is transmitted 2 ms early, since the first pulse of the group is always on time. At present, only Cape Fear and Johnston Island (Central Pacific chain) transmit identifiers. It is planned that other chains will follow this pattern as they become synchronized later this year.

Presently, the observatory is controlling the time of transmissions from the East Coast and the Central Pacific Loran-C chains,[11] from the Northwest Pacific chain,[12] and from the North Atlantic and Norwegian

V. Coincidence interval T and synchronization status for current Loran-C chains

Chain	T, seconds	Synchronization Status*
East Coast	1	operational now
Central Pacific (Hawaiian)	149	operational now
Mediterranean	199	indefinite
North Atlantic	793	operational now
Northern Pacific (Alaskan)	399	indefinite
Norwegian Sea	797	operational now
Northwest Pacific	997	operational now
Southeast Asia	497	indefinite

*Source: U.S. Naval Observatory. Information subject to change.

Sea chains.[13] Phase values published by the USNO of observations with reference to the beginning of the Loran-C pulse from each master station provide corrections to about 1 μs relative to the master clock.

Synchronizing a clock to Loran-C

Synchronization of a clock to Loran-C transmissions is a two-step procedure. External means must be provided for initially setting the clock to within one half of a repetition period to resolve the ambiguity inherent in a pulsed system. For the currently synchronized chains, the half-period interval varies from 30 to 50 ms. Resolution to this degree is obtained from standard HF or VLF time transmissions.

After the period ambiguity is resolved, the clock can be synchronized to Loran-C. This is accomplished by comparing the time of arrival of the Loran-C pulse with the seconds' tick of the clock at a TOC. For the East Coast chain, a TOC occurs every second and, thus, a measurement can be made at any second. Other chains have TOCs only once every T seconds and, consequently, a device such as an epoch monitor (Fig. 8) must be used to facilitate the synchronization procedure.

Precise synchronization to the USNO master clock requires a knowledge of propagation delay for the particular transmitter–receiver geometry. This delay can be calculated for ground-wave conditions to within about a microsecond over seawater and a few microseconds over land, and to within about ± 20 μs under sky-wave conditions. Measurement of the delay by a portable precision clock will provide a ground-wave synchronization accuracy limited principally by the stability of that clock. By use of certain techniques,[9,10] a sky-wave synchronization accuracy of a few microseconds can be achieved over many paths. The USNO will supply computed propagation delays, on request, to qualified users.

The mechanics of station clock synchronization to Loran-C transmissions may vary according to the type of receiver being used, and the timing precision required. Reference to the configurations shown in Figs. 9 through 12 will help to understand the various procedures. Automatic receivers provide a repetition-rate pulse train that is synchronized to the time of arrival of the Loran-C signal to within 0.1 μs. Use is made of a time-interval counter whose count is initiated by a TOC pulse selected from the station clock by an epoch monitor and terminated by the repetition-rate pulse from the receiver. Once the clock has been set by external reference to within half of a repetition period, the counter reading, accurate to 0.1 μs, will equal the algebraic sum of the propagation delay, receiver delay, emission delay, and the clock error. Since any variations in ground-wave propagation delay, receiver delay, and emission delay are less than 0.1 μs, variations in the counter reading over a period of time will be a direct indication of the local clock drift as referenced to the Loran-C transmissions.

Visual receivers do not provide a pulse output for direct measurements. The operator must visually adjust the timing of pulses from a local Loran-C repetition-rate generator so that they coincide with the beginning of the received Loran-C pulses. Once this has been adjusted, clock synchronization is performed in the same way as if the automatic receiver were used. Accuracy is dependent on the ability of the operator to adjust the local pulses to the beginning of the Loran-C signal as viewed on an oscilloscope and is dependent on the signal-to-noise ratio at the receiver. The degree of accuracy can be enhanced by integration using photographic time exposure.

If proper cycle selection is accomplished visually, synchronization can be achieved to within about a microsecond. Phase-tracking receivers will provide a pulse output that is automatically positioned to bracket three cycles of the Loran-C signal to within 0.1 μs. Since the receiver does not possess automatic cycle selection,

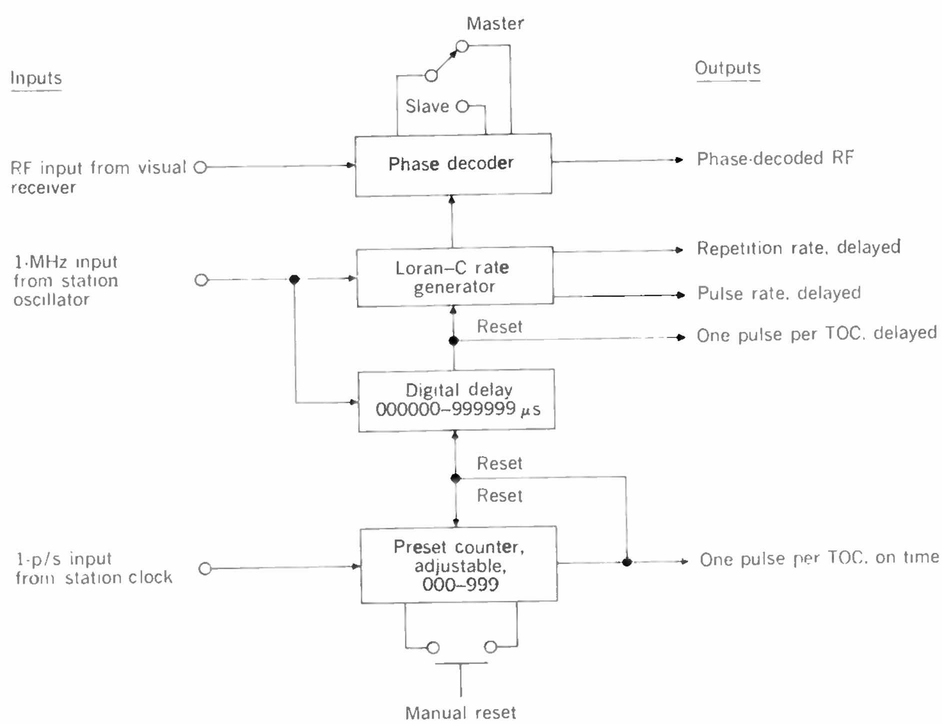


FIGURE 8. Simplified block diagram of an epoch monitor system. Taking a 1-p/s input from the station clock, the unit produces an output each TOC after being manually reset at a TOC. This output is delayed an integral number of microseconds equal to the total of the propagation and system delays and used to reset a rate generator. The rate generator output should then be coincidental with time of arrival of Loran-C pulses.

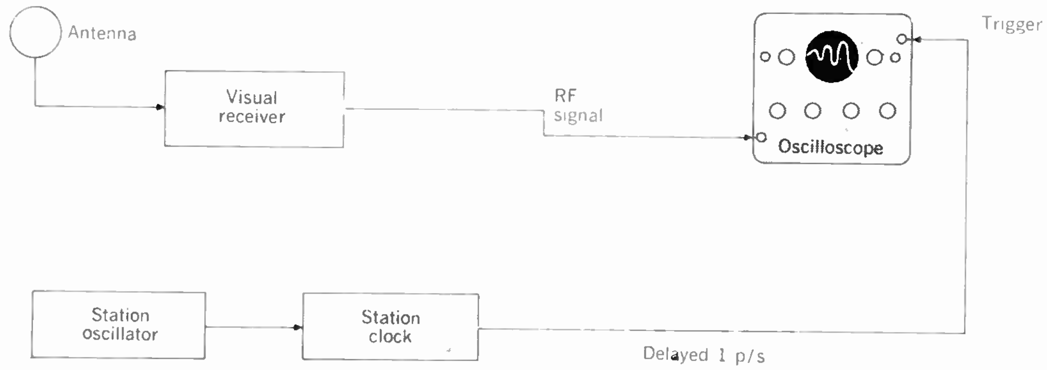


FIGURE 9. Simple visual timing system. This configuration can be used within a few hundred kilometers of a master station transmitting 1-p/s identifiers or within that range of any station on the East Coast chain. The useful range may be expanded by means of photographic integration. Accuracies to $\pm 20\ \mu s$ for ground waves can be achieved, depending on range and viewing technique. A 1-p/s delay from the station clock is used for positioning the Loran-C signal. A clock not possessing the calibrated delay feature may be used if the accuracy of delays obtained from reading the oscilloscope calibration is sufficient.

FIGURE 10. Visual timing system, recommended for use in any sky-wave situation and for ground waves in which automatic-receiver accuracies are not required. In addition to the selection of TOC pulses, an epoch monitor system as shown in Fig. 8 produces a pulse rate (groups of eight trigger pulses, spaced 1 ms apart, at the repetition rate) that is reset to the delayed 1 p/s, and also phase decodes the RF signal. The pulse-rate output may be further delayed in 1-μs steps for repositioning of the viewed pulse in the event the station clock is off. Accuracies are basically limited by the ability to cycle-select ($\pm 20\ \mu s$ for ground waves) and may be improved by the use of photographic integration techniques.

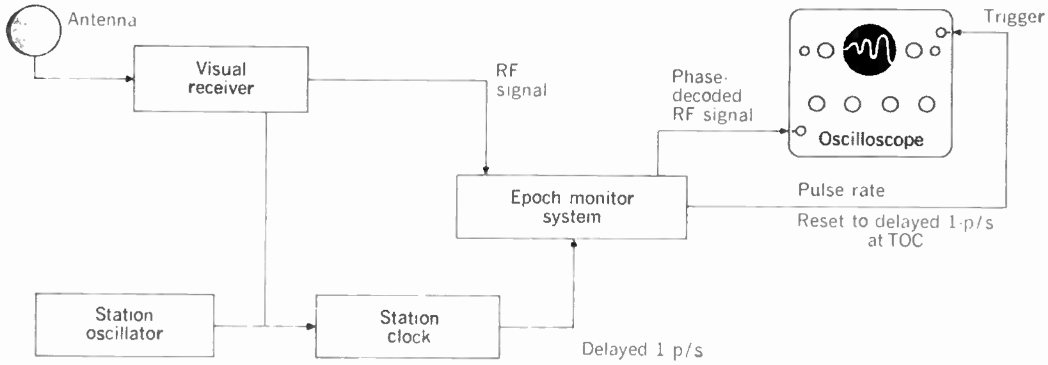
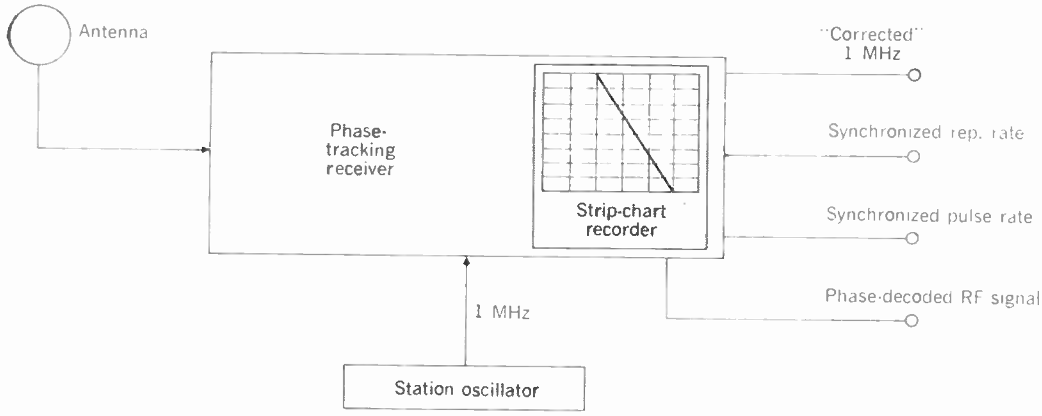


FIGURE 11. Phase-tracking system, which provides a record of the local-oscillator phase drift with respect to Loran-C. Recommended for use within the ground-wave range of a Loran-C station, it provides a record free of diurnal shift that can be used to compare the station oscillator to the cesium reference at the Loran-C station to within one or two parts in 10^{12} in a 24-hour period. Additional outputs are provided for timing purposes, to be used in the same manner as with an automatic receiver. Accuracies will be dependent upon the ability to cycle-select visually and, in general, will be within the range of $\pm 20\ \mu s$.



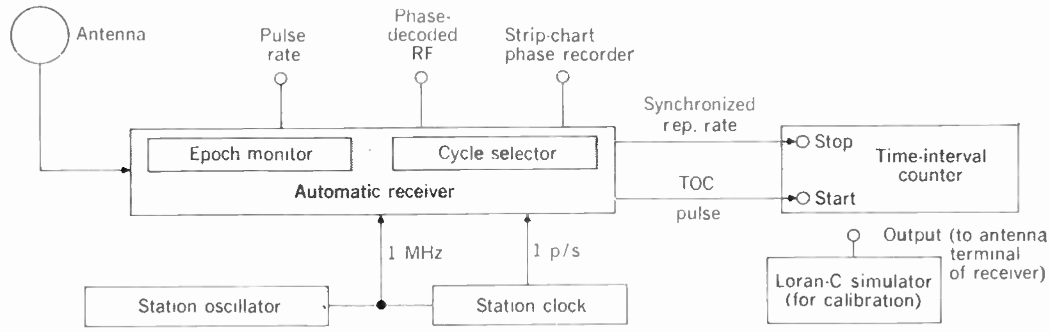


FIGURE 12. Automatic receiver system. Depending on the particular chain to be monitored, various automatic-receiver configurations may be used. When within range of the East Coast chain, an epoch monitor is unnecessary since a TOC occurs every second. The 1-p/s counter is then started by the clock. The configuration shown is for the general case, in which odd-repetition-rate signals are received. The time-interval counter may be replaced by an epoch monitor system as described in Fig. 8, and synchronization can be determined by means of oscilloscopic time comparison of the receiver and epoch monitor system repetition-rate pulses. An automatic receiver has cycle-selection capability, and accuracies to 0.1 μs are readily attainable. A Loran-C simulator is useful for providing system calibration.

synchronization must be accomplished visually. If cycle selection is uncertain, the synchronization accuracy is consequently reduced by the amount of the uncertainty.

Of particular use with visual receivers is an epoch monitor system such as shown in Fig. 8. In addition to selecting TOC pulses automatically, it contains a Loran-C repetition-rate generator that is reset by a delayed TOC pulse for use in viewing the Loran-C signal, thereby correctly positioning the Loran-C for optimum viewing. Radio-frequency input from the visual receiver is phase decoded in either the master or slave format for oscilloscope viewing, using the delayed pulse rate output as the trigger.

The techniques of clock synchronization to Loran-C can be substantially simplified when used with a station that has a simple repetition rate such as in the East Coast chain, or when located within range of a master station of any chain that transmits 1-p/s identifiers. In these cases, the oscilloscope can be triggered by a delayed 1 p/s from the station clock, and the Loran-C pulse from a visual receiver positioned by adjusting the delay. Because the one-per-second sweeps are difficult to view with precision, it is usually necessary to use photographic time exposure for accuracies better than about ± 30 μs.

Conclusions

It has been shown how Loran-C signals can be used for clock synchronization over long distances to accuracies as fine as 0.1 μs. Low-frequency propagation is reliable and definite schedules for station personnel can be maintained. The complexity (and cost) of a Loran-C timing system will vary with station location and accuracy requirements. For many applications, simple visual equipment may be used to provide a substantial improvement in synchronization capability, compared with other techniques, without imposing complex procedures on station personnel.

Frequency comparison using Loran-C ground waves can provide measurements to within a part or two in 10^{12} over a 24-hour period. The absence of diurnal shift suggests numerous experiments in which oscillators distant from one another can be slaved to a common stable reference.

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Railroad electrification: past, present, and future

Competition of the diesel; modern signaling, communications, and safety devices; prospects for the future

The status of present-day rail systems in the U.S. is that of a "dynamic hiatus," in which outmoded rights of way and rolling stock—equipped with sophisticated electronic devices—remain in service pending fulfillment of the much-advertised high-speed ground transportation dream

Gordon D. Friedlander Staff Writer

Today, the primary motive power unit employed by U.S. railroads is the diesel engine. The steam locomotive has been phased out, and the use of electric traction has declined markedly. Until recently, the trend was against the further extension of electrified operation because of high initial costs. Further, the diesel locomotive can be operated throughout a railway system—in both electrified and nonelectrified zones. Now, however, with the advent of extensive electric power grids, rectifier locomotives, and ambitious plans for extensive rapid-transit systems, electrified operation has obtained a new lease on life. Signal system development has brought notable improvement in railroad safety and operations. Most important in this category is centralized train control, by means of which a single tower can control all switches and signals over more than a thousand kilometers of mainline track. And with automatic train stop equipment and speed control, a train running through a stop signal or exceeding a speed limit can be electronically stopped or slowed, thereby eliminating the possibility of human failure. Two-way radio communications have done much to expedite freight-train operations. Many locomotives, cabooses, and signal towers are equipped to permit train conductors to talk to engineers or tower personnel, and to receive orders while en route.

Railroad electrification in the United States at its peak never exceeded about 4000 route-kilometers (2500 route-miles) for three significant reasons:

1. The lack of adequate hydro facilities for the production of low-cost power and the consequent dependence upon noninterconnected steam-electric generation stations (during the first three decades of the 20th century) that required long transmission lines and many substations to serve a railroad's electrified territory.
2. The adoption of 25-Hz alternating current for electric traction motors, which required expensive conversion equipment to handle the standard 60-Hz current carried on the transmission lines.
3. The high initial capital expenditures for transmission lines, substations, catenary or third-rail systems, locomotives, or multiple units required in the electrification of multiple-track rights of way over relatively short interurban distances, which militated against extensive electric division operation.

In defense of reason 2, it should be mentioned that, in the early years of electrification, rotary converter and motor designs did not lend themselves to 60-Hz power without the incorporation of a complex system of speed-reduction gears between the motors and axles. For example, the New York City subways (IRT and BMT lines) used 25 Hz to drive their 600-volt dc converters until the Independent (IND) system was placed in service in the

FIGURE 1. Two modern Penn Central diesel–electric road and switching locomotives coupled together for operation as a multiple unit by engineman in the front cab.

late 1930s. At that time, 60-Hz power was purchased from the Edison Company and mercury-arc converters were used in the IND operation.

The pattern of railroad electrification, at best, has been sporadic and incomplete on major systems. For example, only about a third of the Penn Central's total trackage is in its electrified territory; the Milwaukee Road has two long—but noncontiguous—electric divisions; and the Norfolk & Western and Virginian Railways had overhead catenaries only for a combined distance of about 200 route-miles (now abandoned in favor of diesel traction).

Advent of the diesel–electric

Although the diesel–electric locomotive had been used to a very limited extent on North American railroads in the 1920s, and as part of several articulated and nonarticulated high-speed long-distance passenger trains (such as the "Pioneer Zephyr" of the Chicago, Burlington & Quincy; the Union Pacific's "City of Portland"; and the Santa Fe "Super Chief") in the 1930s, it was not until 1946 that the diesel locomotive became a standardized type of motive power that rapidly superseded the steam locomotive—and some electric service.

In the diesel–electric locomotive, power is developed by a diesel engine driving a generator, which in turn feeds electric traction motors (nominally 600-volt, series-wound) mounted on each axle. This type of power transmission is smooth and efficient at all speeds and under most load conditions. A number of diesel units—depending upon the type of train and grades en route—can be coupled together (Fig. 1) and operated as a multiple unit by an engineman in the front cab.

Electric vs. diesel–electric. The primary advantage of the diesel–electric is its versatility: it can be used over any division of any main line or branch line of any standard railroad system in the United States, Canada, and Mexico. On the other hand, the diesel–electric must carry its own power plant and fuel[1] and therefore reaches limitations on size and weight at a power output of about 3000 kW on six axles. But an electric locomotive of corresponding weight can be built at a rating of 5200–6000 kW. In short then, one electric can do the work of two diesel–electrics. Also, the initial cost of an electric locomotive is approximately 20 percent less than that of a diesel-electric with the same power rating.

In the area of maintenance costs, the electric has the edge: a 16-cylinder diesel engine has more than 9000 parts, of which about 2700 are moving; the equivalent transformer of the electric locomotive has no moving parts. Thus there are electric locomotives, placed in service more than 40 years ago, still providing excellent performance.

Faster schedules are also possible with all-electric traction because of higher acceleration rates and shorter turn-around time (diesels require refueling). Further, electric motive power is cleaner and quieter.

Recent developments in power generation and electric traction

Perhaps the most notable advance working to the advantage of present-day and future railroad electrification has been the development of the extensive interconnected power pools that form complex high-capacity grids throughout the U.S., plus the concurrent increase in size and capacity of individual electric utility systems. These factors have reduced transmission problems, have diminished the need for numerous railroad substations, and have lowered the price of electric energy.

One of the most significant recent developments in electric traction was the rectifier locomotive (see the first installment, July IEEE SPECTRUM), which paved the way for the application of commercial 60-Hz current to all railroad electrification. The implications of this development are obvious: capital investment now can be reduced by eliminating the expensive conversion equipment required for 25-Hz systems and the attendant operating and maintenance costs required for such installations.

Investigations of the Railroad Electrification Committee

In 1965, the electric utility industry, through the Edison Electric Institute, established the Railroad Electrification Committee for the purpose of determining the technical and economical feasibility of future railroad electrification projects. Specifically, the study included:

1. A review of the technical problems involved in the supply of large, varying single-phase loads from three-phase commercial systems.
2. Recommendations as to financing arrangements for new railroad electrification projects.
3. Suggestions as to optimum tariff arrangements.

In the first area, the general findings confirmed that most utility systems could handle the large, single-phase loads without serious power imbalances. For example, detailed analyses of both the Pennsylvania Railroad's existing electrified territory and a hypothetical electrified line on the New York Central System between New York City and Cleveland (a route selected because its length, topography, and traffic density appeared ideal for electrification) indicated that current and voltage imbalances would be well within pre-established limits.

A study group of the committee found that no significant advances have been made in catenary design in the United States for more than 30 years. In view of this, funds were provided by the EEI to investigate economic and efficient catenary design for train speeds up to 160 km/h, and further, to make provisions in such designs for eventual speeds of 240 km/h.

Using the results of overall system design, the committee will derive detailed and accurate cost estimates, which can be used in considering the total problem of railroad electrification.

Railroad communications

The story of railroad electrification, or "electronification"—if the writer may coin an awkward word—would not be complete without describing the complex communications systems that are used on first-class railroads throughout the United States.

Telegraph and telephone. The railway telegraph dates back to 1851, when it was first used for dispatching trains; the telephone was first tested for railroad communications in 1877.

Modern railways are among the larger operators of electrical and electronic communications facilities. For instance, the dial telephone network of the Southern Pacific system encompasses the entire western area of the U.S., and it permits personnel anywhere on the railroad and its affiliated companies (Union Pacific and the Milwaukee Road) to dial directly to offices at any location on the 22 400-km rail system that serves 12 states. Other railroads have similarly extensive telephone systems along their rights of way.

The Morse telegraph, originally used in North America for all railway business messages—as well as train dispatching—eventually was relegated to use only on some secondary and branch lines, and train dispatching was then accomplished almost entirely by telephone or by centralized traffic control signaling (to be described later in this article). Thus for message communication, other than that involved in train dispatching, most U.S. railroads came to rely heavily on the Teletype and teleprinter, and many railway systems installed teleprinter networks to interconnect all stations, engine houses, yard offices, and general offices. In addition to the exchange of routine messages, the teleprinter system is used for the transmission of the complete train "consist" (list of passenger or freight cars in the train) from the point of origin to the next station on its route. By having the exact train consist, the destination terminal can plan its switching operations well in advance of a train's arrival.

Simultaneously, the same train consist may be transmitted to the railroad's general offices, where it can be used to inform customers of the in-transit progress of their shipments. Duplicate copies of the list can be filed by the accounting department for billings.

Role of computers. Since 1960, an ever-increasing number of railroads have been moving toward the concept of integrated data processing, in which operations and accounting data of many types can be fed by telecommunications from outlying data-line terminals to a computer center, usually located at the railroad's general offices. Central data processing, however, requires a large number of communications circuits. Thus the capacity of a single pair of telegraph lines may be increased many times by the superposition of a number of electronic carrier circuits, each operating in a discrete frequency range. But demands for circuits, in some cases, have even exceeded the capacity available from carrier equipment. Therefore, some of the larger railroads have adopted microwave transmission to supply the many channels needed for direct-dialing systems, teleprinter, and data-processing circuits.

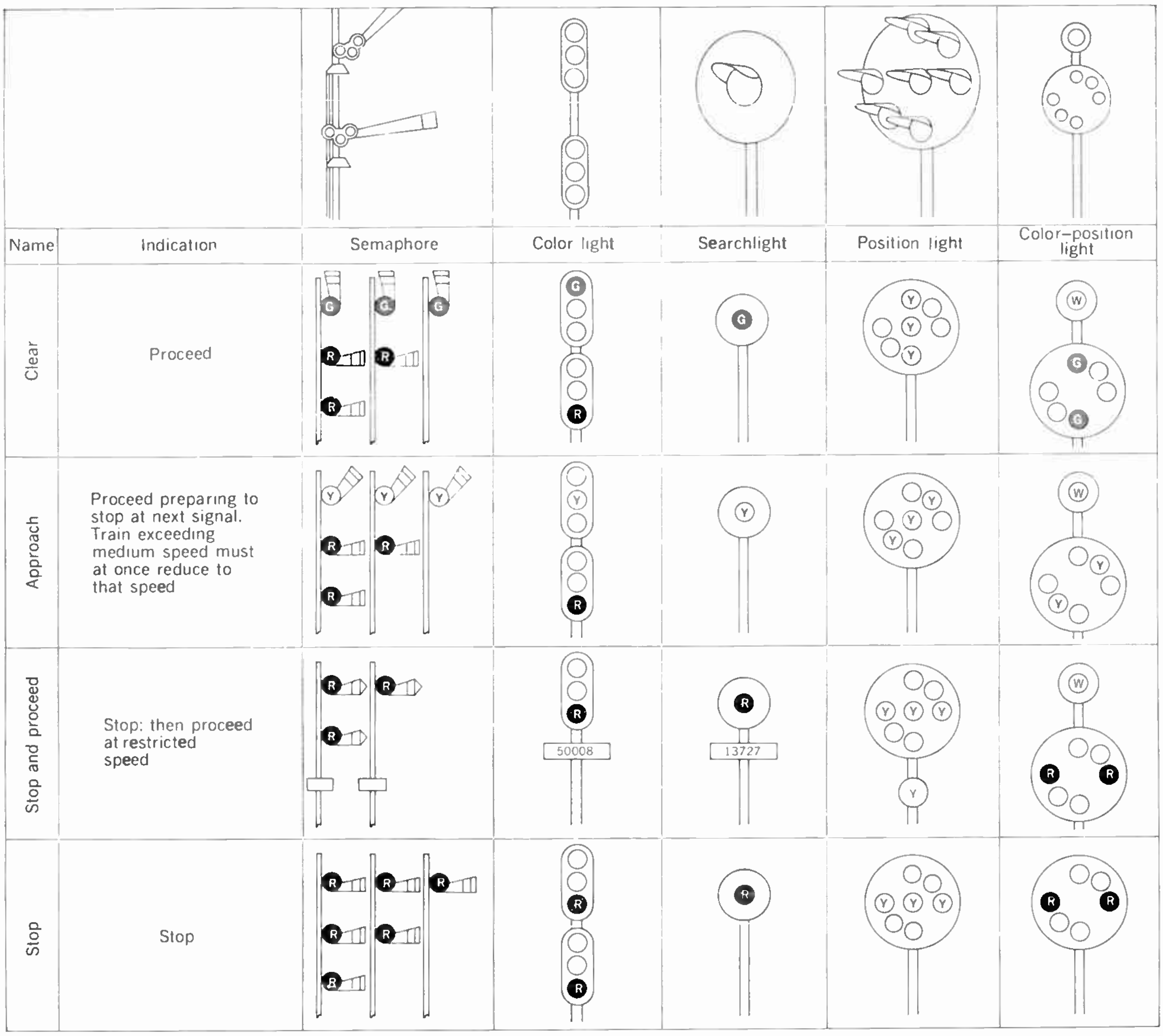


FIGURE 2. Standard signal indications and aspects used on U.S. railroads. Lamp colors are G, green; Y, yellow; R, red; and W, white. The three columns under "semaphore" show how the same indication may be given with one, two, or three signal heads on the same mast (any of the other types of signals may also be combined in the same manner); two- and three-head signals generally are used at junctions and passing sidings. A "stop-and-proceed" signal is designated by a number plate on the mast below the signal head, by a marker light, by a pointed semaphore blade, or by a combination of these features.

Radio. In 1959, the Pacific Great Eastern Railway, between Vancouver and Dawson Creek (Canada), became the first line to use microwave radio for all wayside communications, with the consequent elimination of most of its wire lines. Other major carriers in the U.S. and Canada, notably the Santa Fe, Southern Pacific, and Union Pacific, also installed extensive microwave systems. Microwave also has the advantage of minimizing communications interruptions in areas subject to heavy sleet storms and snowfalls, which can bring down conventional wire lines.

Following World War II, U.S. railroads began the widespread use of VHF radio communications. In freight operations, for example, VHF permits communication between the locomotive crew and the conductor and brakeman in the caboose of a long train, between two trains, and between the train dispatcher and wayside stations and trains. In terminals, two-way radio greatly speeds yard switching work, because it allows the yardmaster to keep in close contact with the yard switch engines. By means of VHF radio, too, widely separated track maintenance crews can maintain contact with each other and with oncoming trains.

Railroad visual signals

Railway signals are a form of communication designed to inform the train crew (in particular, the engine crew) of track conditions ahead, and the procedure to follow in the operation of the train.

The earliest form of visual signaling consisted either of a lamp by night or a flag during daylight hours. The first practical movable signal was the semaphore (Fig. 2), originally adopted in 1841; it provided "stop," "proceed with caution," and "all clear" indications. And among the early types of widely used signals in the U.S. was the "highball" type, in which a large colored ball was hoisted to the top of a pole to inform the engineman that the train could proceed.

The first attempts at interlocking switches and signals were made in France and England in the 1850s; these were introduced to the United States in the 1870s. Interlocking at crossings and junctions prevents the signalman from displaying a clear signal for one route when clearance has already been given for a conflicting route. Essentially, then, it is an early example of a protective system. Another forward step was the introduction of train operation on a "headway" interval, or block system, during the 1880s.

The next major advance was the application of electric power to signaling. The experience gained with mechanical interlocking led to the eventual development of all-electric interlocking. This, in turn, led to interlocking in which the controls are actuated by electric relays.

Types of signals. A refinement in the design of the semaphore signal was the incorporation of the color light in the configuration. This was soon followed by the use of the color light only (Fig. 2), with a separate bulb and lens for each aspect (clear, caution, and stop). By the 1960s, both the semaphore and the color light signals were generally superseded in the U.S. by the searchlight type, which employs only a single lens and bulb; the different colors are displayed by means of roundels or color filters that are rotated in front of the lamp.

Two other types of signals are used in the United States: the position light (used throughout the Pennsylvania Railroad system), in which rows of yellow lights duplicate the positions of the semaphore arms; and the color-position signal (used on the Baltimore & Ohio), which is a combination of two color lights that simulate semaphore positions (Fig. 2).

Automatic block signals. In block signaling, the track right of way is divided into sections, and a train is not permitted to enter a section until the train ahead has left it. The subsequent use of electric interlocking removed the factor of human error by making it impossible for the "line clear" indication to be given for a section already occupied by a train.

Of more recent vintage is automatic block signaling, in which track circuits are short-circuited by the leading wheels to trip the signals in the rear of the train—and on single-track lines in front as well—to a mandatory stop position or color. A track circuit is made by the two rails of a section of track, each of which is insulated at its butt-end splice points. Electric current, fed into the track section at one end, flows to a relay at the opposite end, and the wheels of any vehicle will then close the circuit and energize the relay.

Centralized traffic control. A logical extension of the route interlocking principle is centralized traffic control (CTC), a system in which trains are guided entirely by the remote control of signals and switches from a central station (Fig. 3). Here, an operator sees the track layout of his division in miniature on his control panel. Lights on the panel show the location and progress of all trains at all times. By pushing buttons and turning dial controls, the operator can direct the movement of trains over distances up to 1000 km.

In CTC, track circuiting is essential so that the position of every train is known. Switches and signals are operated by coded electric circuits, thereby reducing the amount of wiring required. Over long distances, CTC substantially increases track capacity by making more effective use of the line. And since CTC eliminates the need for written train orders or manual operation of block signals, it permits the elimination of telegraph or signal stations on heavily trafficked lines. On lines carrying light traffic, most of the benefits of CTC can be obtained, at less cost, by having the signals controlled from the central station and the switch points operated manually by the train crews.

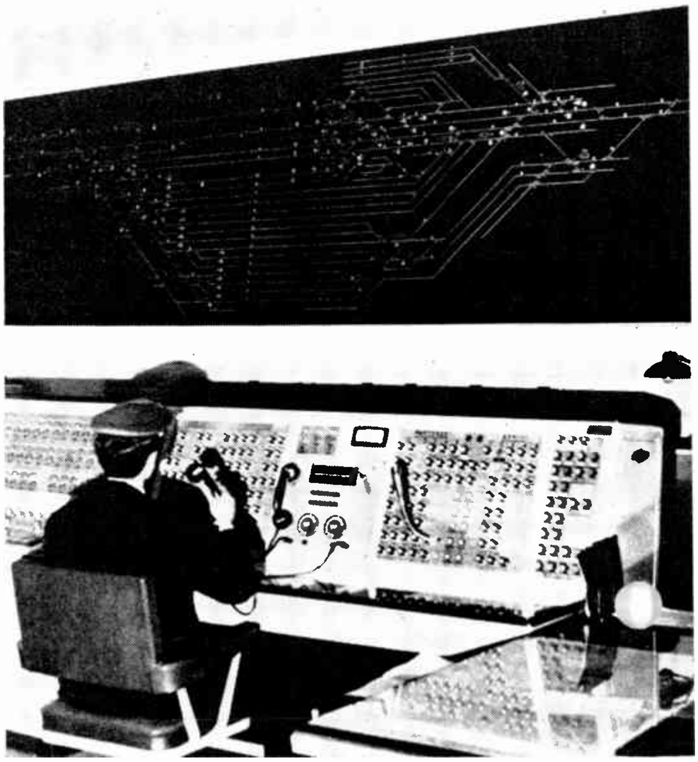


FIGURE 3. Typical centralized traffic control (CTC) system at a freight marshaling yard, from which trains are guided entirely by the remote control of signals and switches from the central station. The track layout, in miniature, is shown on the panel above the operator.

FIGURE 4. The WABCO Type 'El' Cab Signal System, in which a visual signal in the locomotive cab (to the left of the engineman) repeats the wayside signal shown at the right.

Automatic train controls

In broad outline, automatic train control (ATC) provides the engineman in the locomotive cab or the motorman at the controls of a multiple-unit train with audible—and sometimes visual—information on track conditions. Should a restrictive signal be ignored, the brakes are applied automatically to stop the train. And several U.S. railroads use *automatic speed control*, a refined form of ATC. In speed control, a miniature visual signal in the cab repeats the wayside signal (or it may be used in lieu of wayside signals). If the train speed should exceed that indicated by the signal aspect being displayed, the brakes are automatically applied to reduce the speed below the maximum permissible level.

Getting down to the "nitty-gritty" principles of operation, circuitry, etc., the details of the Westinghouse Air Brake Company's (WABCO) version of these systems will be described in the following sections:

Type 'EL' Cab Signal System. This system was developed by Union Switch & Signal (a division of WABCO) to provide in the locomotive cab a continuous, constantly visible signal (Fig. 4), which instantly notifies the engineman of any change in conditions ahead, regardless of the position of the locomotive with respect to wayside signals.

The continuous-code feature of the cab signal system affords both increased safety and improved train handling. Under conditions such as fog, snow, sleet, heavy rain, or smoke, which may obscure wayside signals, the cab signal repeater is always plainly visible to the engine crew. Thus the chances of missing or misinterpreting wayside signals are eliminated and the engineman can maintain scheduled speeds regardless of prevailing weather conditions. The engine crew operates the train under the continuous authority of the cab signal because the indication may be received at any point en route and is not confined to specific track zones. Fail-safe reliability is ensured in all continuous cab signal systems by inductive coupling of the equipment to the actual running rails. The failure of cab signaling current in the rails will trip the signal to the most restrictive (stop) indication.

In addition to its ability to handle the operational cab signal indications, the coded system of control provides three operating characteristics that materially improve safety conditions and equipment protection: better control at switch points, detection of broken rails, and prevention of inductive interference.

The coded continuous cab signal system may be divided into two basic components:

1. The *wayside portion*, which supplies the proper coded alternating current in the rails under the locomotive receiver.

2. The *engine portion*, which is controlled inductively from the coded alternating current in the rails and includes the necessary equipment to provide the cab signal aspects, the audible warning, and the train-control features such as automatic stop and speed control.

These components are universally applicable to diesel-electric and all-electric ac or dc propulsion systems, and they may be used in conjunction with any existing type of wayside signal system.

Principle of operation. The Type 'EL' system provides from two to four signal indications. Coded alternating current in the running rails passes under the receiver unit (mounted ahead of the locomotive's leading wheels), through the wheels and axles, and returns via the rail adjacent to its source. The cab signal indications are obtained by interrupting the alternating current in the rails at various rates of speed. Depending upon wayside conditions in advance of the train, the current is interrupted by means of code-transmitter relay contacts. These codes may be measured by their number of interruptions per minute. As shown in Table I, the code values employed in a typical color-light network vary from 75 to 180 pulses per minute.

I. Typical signals and codes used on Type 'EL' cab systems

Cab Signal Indication	Code, interruptions per minute
Clear (green)	180
Approach—medium (yellow-green)	120
Approach (yellow)	75
Restricting (red-yellow)	no code

The "restricting" indication (actually the most urgent indication of the system) is obtained not only when the ac track-circuit current is cut off, but also in any track circuit in which the current is steady in value and is not interrupted at a code rate. Thus the system inherently affords protection from interference of an unsafe character by foreign current because the locomotive-carried apparatus is designed to respond selectively *only* to track current that is periodically interrupted at the pre-established code frequencies.

Voltages of the same frequency and code rate as the rail current are induced in the receiver coils carried on the locomotive and these voltages, after amplification, are used to operate a code-following relay, called the "master" relay, which, in turn, governs decoding units that are selectively responsive to the code rate at which the master relay is operated. The associated decoding relays then control the cab visual signals and the warning-whistle (audible signal) valve magnet. The acknowledging relays are also controlled by the decoding relays by requiring the engineman to "acknowledge" a change in the cab signal indication (by reducing speed or stopping) when the change is to a more restrictive indication.

System performance. Figure 5 shows how the cab signal indication changes as a train approaches another train ahead. Let us assume that train B is entering the first of four blocks, and that the fourth block is occupied by train A. The cab signal in train A displays the "clear" (green) indication, and as the engine passes the green wayside signal, there is no change in the cab signal, which remains green throughout the first block.

When the next wayside signal, at "approach—medium speed" (flashing yellow), is passed, the cab signal changes to "approach—medium" (yellow over green). The restrictive condition is called to the engineman's attention by the sounding of a warning air whistle, which continues to sound until the engineman operates the "acknowledgment switch" that is located within his convenient reach. He then reduces the speed of his train in accordance with the rules. If, for any reason, the engineman fails to acknowledge, the continued warning sound directs the fireman's attention to the need for action.

When the third wayside signal, holding at "approach" (steady yellow), is passed, the cab signal changes to "approach" (yellow) and, as before, the warning whistle

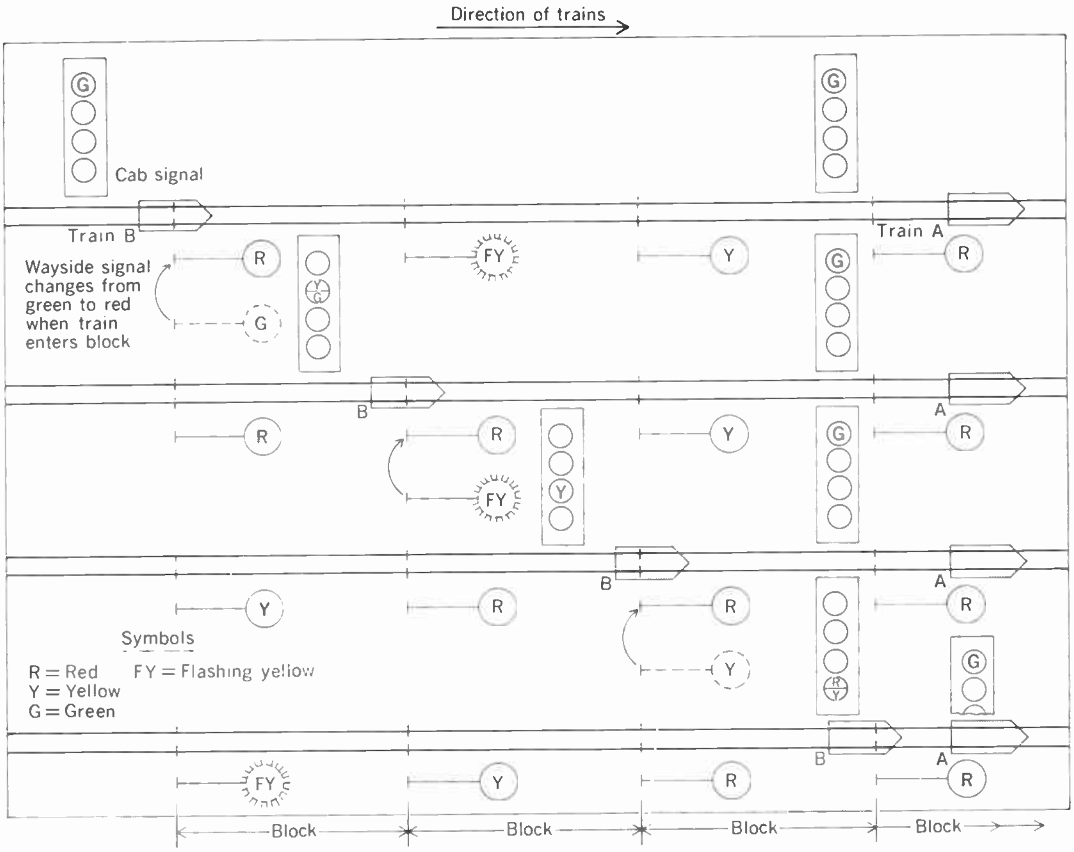
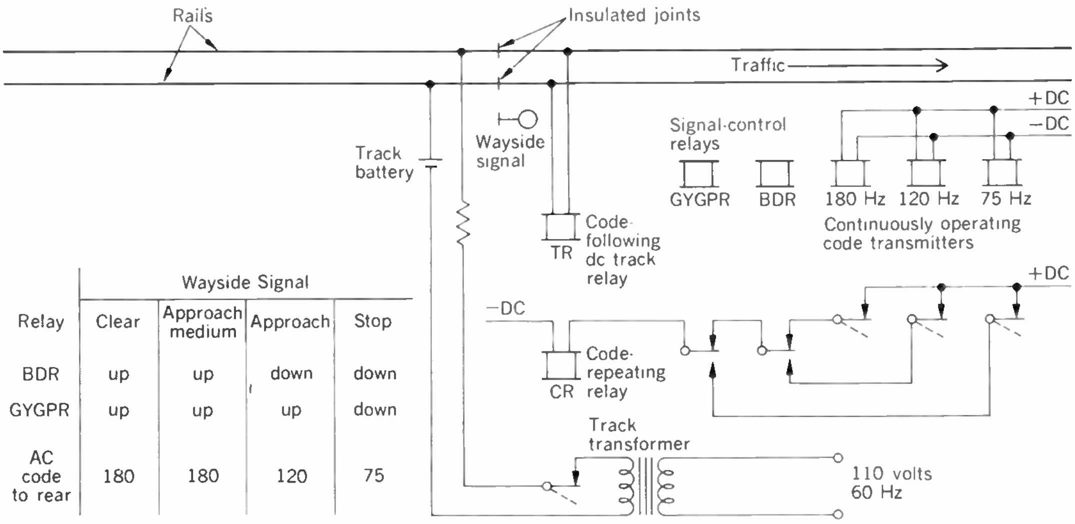


FIGURE 5. Diagram showing how cab signal indications change as a train approaches another train ahead.

FIGURE 6. Block diagram of a typical track-circuit control of cab signal indications.



Relay	Wayside Signal: Clear	Approach medium	Approach	Stop
BDR	up	up	down	down
GYGPR	up	up	up	down
AC code to rear	180	180	120	75

blows and continues to do so until the acknowledgment switch is operated.

The fourth wayside signal will be at "stop and proceed" (red) because the block it governs is occupied by train A. After first coming to a full stop—in accordance with railroad operating rules—train B may proceed slowly into the occupied block, but the engineman must be prepared to stop his train within range of vision. As the stop-and-proceed wayside signal is passed, the cab signal will change to "restricting" (red over yellow), and the whistle will blow until acknowledgment is completed.

A typical circuit for wayside control of 60-Hz four-indication cab-signaling rail energy is shown in Fig. 6. For simplicity of presentation, the wayside signal control circuits are omitted. Both coded direct current from the track battery for wayside signal control and coded alternating current from the low-voltage winding of the track transformer for cab signal operation are supplied

FIGURE 7. Streamlined front-end view of two of the new permanently coupled "Metroliner" high-speed multiple units soon to be placed in service on the Washington–New York run.

to the exit end of the track circuit. The ac code transmitted to the rear from the signal location is determined by the position of the signal-control relays, which, in turn, are dependent upon the condition of the track ahead. From a perusal of Fig. 6, and its associated table, it can be seen that when the wayside signal displays "clear," a code of 180 interruptions per minute will be fed to the track circuit to the rear. When the wayside signal is at "approach—medium" (flashing yellow), the alternating current will be coded at the 120-per-minute rate; and when at "approach" (yellow), it will be coded at the 75 rate. When the wayside signal is at "stop" (red), the alternating current will be coded at the 75 rate.

When a train enters an occupied track circuit, no code will be received aboard the locomotive because the rail current will be shunted by the wheels and axles of the train ahead. And, as previously mentioned, any hazardous or abnormal situation such as a broken rail, broken wire, open switch, loss of power, etc., that produces a steady (uncoded) ac rail current, will trip the visual displays to the most restrictive (stop) signal indication.

Although the color-light signal system was used in the foregoing example, the Type 'EL' signals are adaptable also to position or color-position lights.

Optional controls. The Type 'EL' coded cab signal system, in addition to the capabilities already presented, may be used for:

Automatic train stop. In this application, the whistle magnet not only starts the whistle alarm, but also initiates automatic braking if, within about six seconds, the engineman does not operate an acknowledgment switch or take other corrective action to indicate that the train is under his full control.

Speed control. Here, a speed governor is added to the locomotive equipment to enforce speed limits in accordance with the cab signal indications. The governor is connected to one of the axles and contains contacts which make and break at specific locomotive speeds. The automatic application of the brakes is controlled by the governor contacts and the cab-signal-control (decoding) relays. In speed-control systems, there is a maximum speed established to each cab signal indication and, if that speed is exceeded, an automatic brake application will occur, unless prompt action is taken by the engineman within a 6-second interval.

High-Speed Ground Transportation Research and Development Act

As mentioned in the first installment of this article, the development of modern high-speed multiple-unit cars[1] was given a great thrust forward with the signing of this legislation into law on September 30, 1965. Following this enactment, the U.S. Department of Transportation initiated the—

Northeast Corridor Demonstration Project. This development, extending from Washington, D.C., to Boston, Mass., is intended to demonstrate the popularity and practicability of frequent, high-speed rail service in relieving highway and air travel congestion in the high-population urban complexes along this route. In a previous article,[2] the writer described the salient features and details of construction, proposed speeds and running-time schedules, and financing for this project.

The 50 initial, self-propelled multiple-unit cars—capable of ultimate speeds up to 260 km/h between New York and Washington—will be called "Metroliners" (Fig. 7). The coach version of these 26-meter-long stainless-steel cars will seat 80 passengers, and the parlor cars will seat 34 persons in individual revolving and reclining chairs. Each car will weigh approximately 76 tonnes.[3]

All 50 cars will contain an askarel-filled forced-air-cooled main transformer together with four 230-kW series dc forced-air-cooled traction motors, and each car will rectify current from the secondary of the main transformer by means of silicon rectifiers. On 25 of these cars, voltage control will be obtained by using four air-cooled ignitron tubes (see Fig. 8 diagram) and series-parallel motor connections. The other 25 cars will be equipped with silicon-controlled rectifiers for this purpose (Fig. 9) and will have all motors in parallel.

The main transformers on all cars are designed to use either 11 or 25 kV, and 25 or 60 Hz. Initially, they will operate on 11 kV, 25 Hz; but, if desired at some future date, shop conversion can readily adapt this equipment to operation at 11 or 25 kV, 60 Hz. The design also features an "en route" changeover capability for mixed voltage and frequency operation on a daily basis when the appropriate devices and controls are installed. All other electric apparatus and equipment is designed to be compatible with these shifts in voltage and frequency.

The Metroliners will be streamlined at each end of permanently coupled two-car units (see Fig. 7), and will operate as multiple units in trains of four to 20 cars, depending upon passenger loads. The cars will accelerate at the rate of 0.54 m/s^2 to a speed of 160 km/h; they will attain a speed of 200 km/h in less than two minutes' time, and 240 km/h in just under three minutes. The initial operating maximum speed, however, will be 177 km/h until track and catenary conditions are upgraded sufficiently to permit safe operation at maximum velocities.

Dynamic braking will be applied in deceleration from maximum speeds down to about 50 km/h, with a smooth transition to electropneumatic braking below that speed.

Other future electrification projects

In the September 1967 issue of IEEE SPECTRUM,[2] the writer discussed the Metropolitan Transportation Authority's METRA project for extending the electrified territory of the Long Island Rail Road, purchasing a large fleet of high-speed multiple-unit cars, and upgrading commuter service.

Another phase of this MTA program is the proposal to extend the electrification of the Penn Central Harlem Division from North White Plains to Brewster, N.Y., a distance of about 48 km; and to install a third electrified track between Mount Vernon and White Plains to im-

FIGURE 8. Diagram of a "Metroliner" power supply circuit for multiple-unit cars equipped with ignitron-rectifier voltage controls.

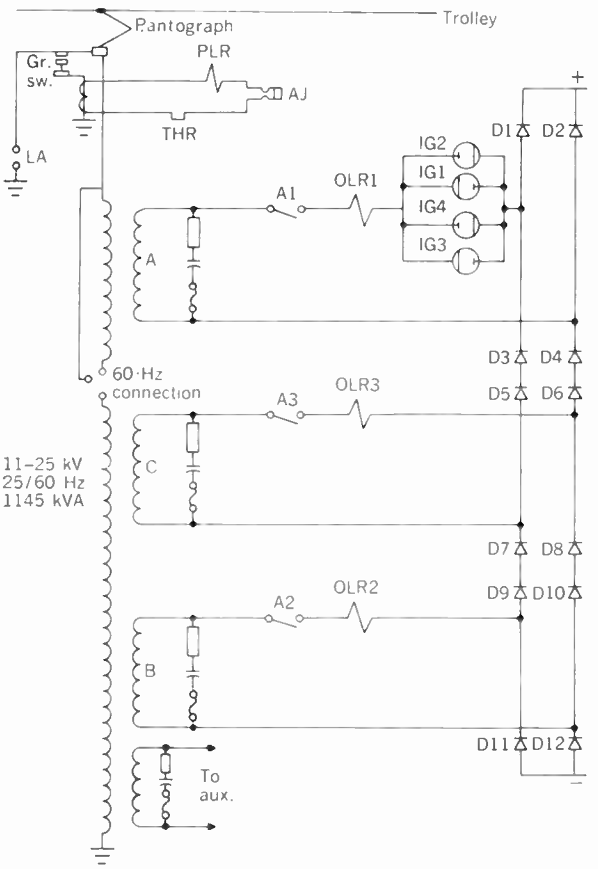
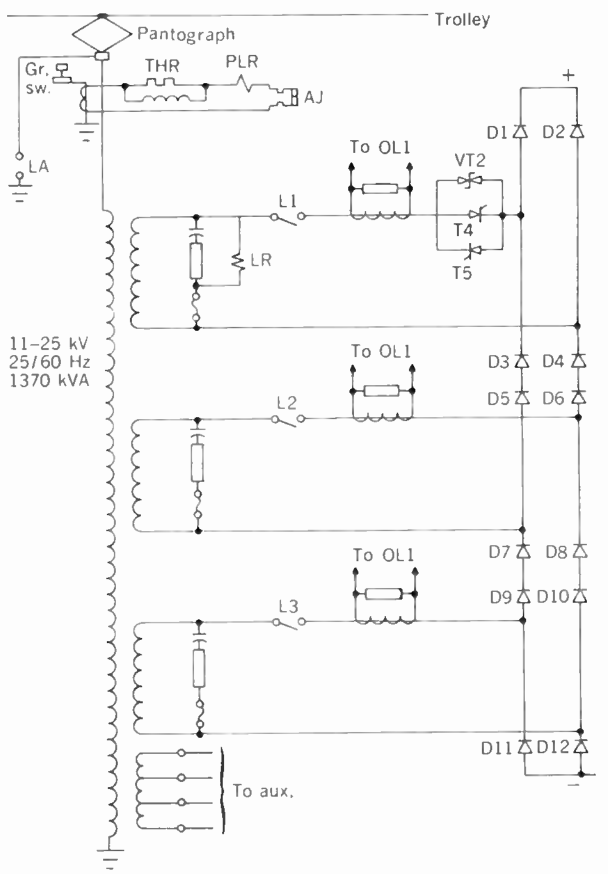


FIGURE 9. Diagram of a "Metroliner" power supply circuit on cars equipped with silicon-controlled rectifiers for voltage control.



prove the commuter service to lower Westchester County.

Southeastern Pennsylvania Transportation Authority. The Penn Central has proposed to SEPTA that mass transit facilities in the Philadelphia metropolitan area (Philadelphia–Wilmington, Philadelphia–Trenton, and Philadelphia–Paoli) be upgraded by an $85 million modernization program on these commuter lines during a five- to ten-year period.

More than $32 million of this sum would be earmarked for the purchase of 124 additional Silverliner multiple-unit cars. Other aspects of the development include:

1. Elimination of grade crossings.
2. Installation of improved signal and switching equipment.
3. Construction of high-level platforms at suburban stations.
4. Installation of new all-welded, electrified tracks.
5. Improvement of commuter parking facilities at suburban stations.

A final feature of this proposal calls for a $5 million appropriation to provide high-speed shuttle service from downtown Philadelphia to the city's International Airport, a distance of about 14 km. This service, using Silverliner cars, would operate largely over Penn Central tracks.

State of New Jersey commuter improvements. According to the Penn Central, 35 new commuter cars are presently under construction (at a total cost of about $9.6 million) to improve the mainline commuter service between Trenton, N.J., and New York City. Also, the state has proposed to electrify—preferably at 25 kV, 60 Hz—the New York and Long Branch section of the railroad to Long Branch, N.J., and to provide multiple-unit cars, similar to the 35 on order, for commuter service to the northern New Jersey area.

Conversion to standard 60-Hz supply

Eight electric utility companies in the PJM pool recently completed a study that indicates the feasibility of furnishing power (at 25 kV, 60 Hz) to the Penn Central's catenary system in New Jersey, Pennsylvania, Delaware, and Maryland, at 24 supply station points from the utilities' 115-kV, or higher, transmission lines. The

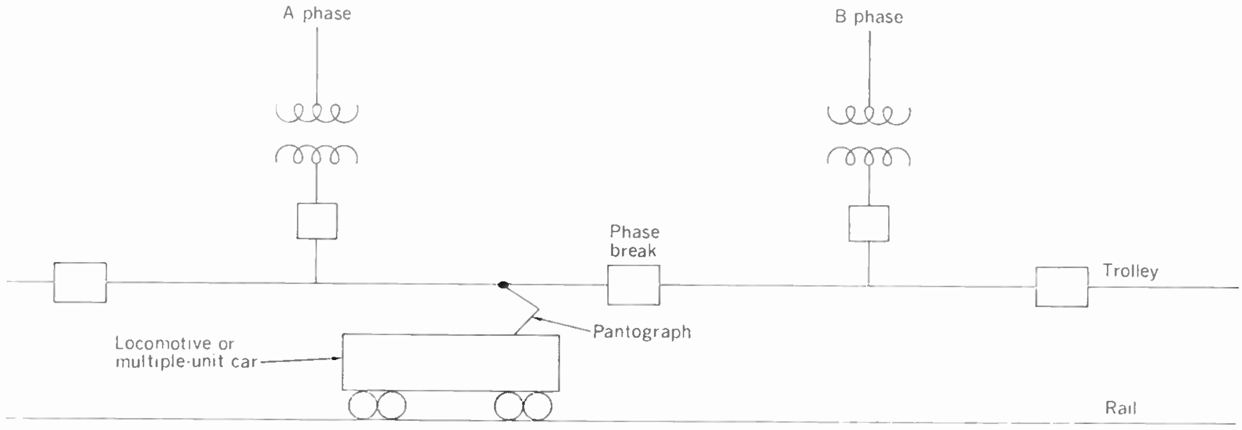
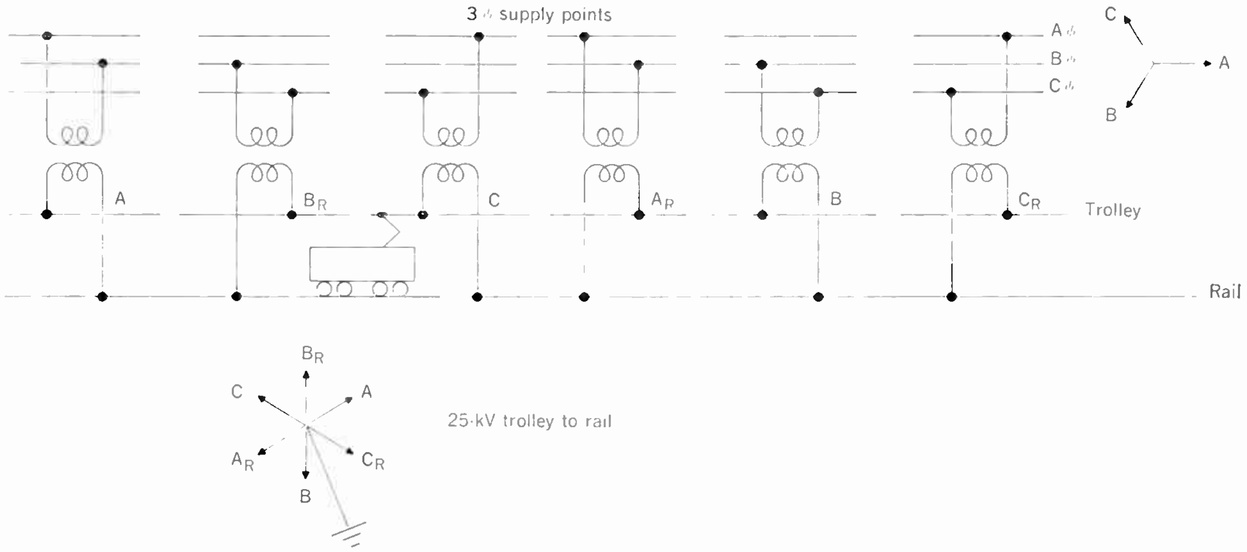


FIGURE 10. Diagram of proposed 25-kV, 60-Hz center-feed system for Penn Central (formerly electrified territory of the Pennsylvania Railroad).

FIGURE 11. Proposed 25-kV, 60-Hz three- to six-phase transformer connection (Penn Central).



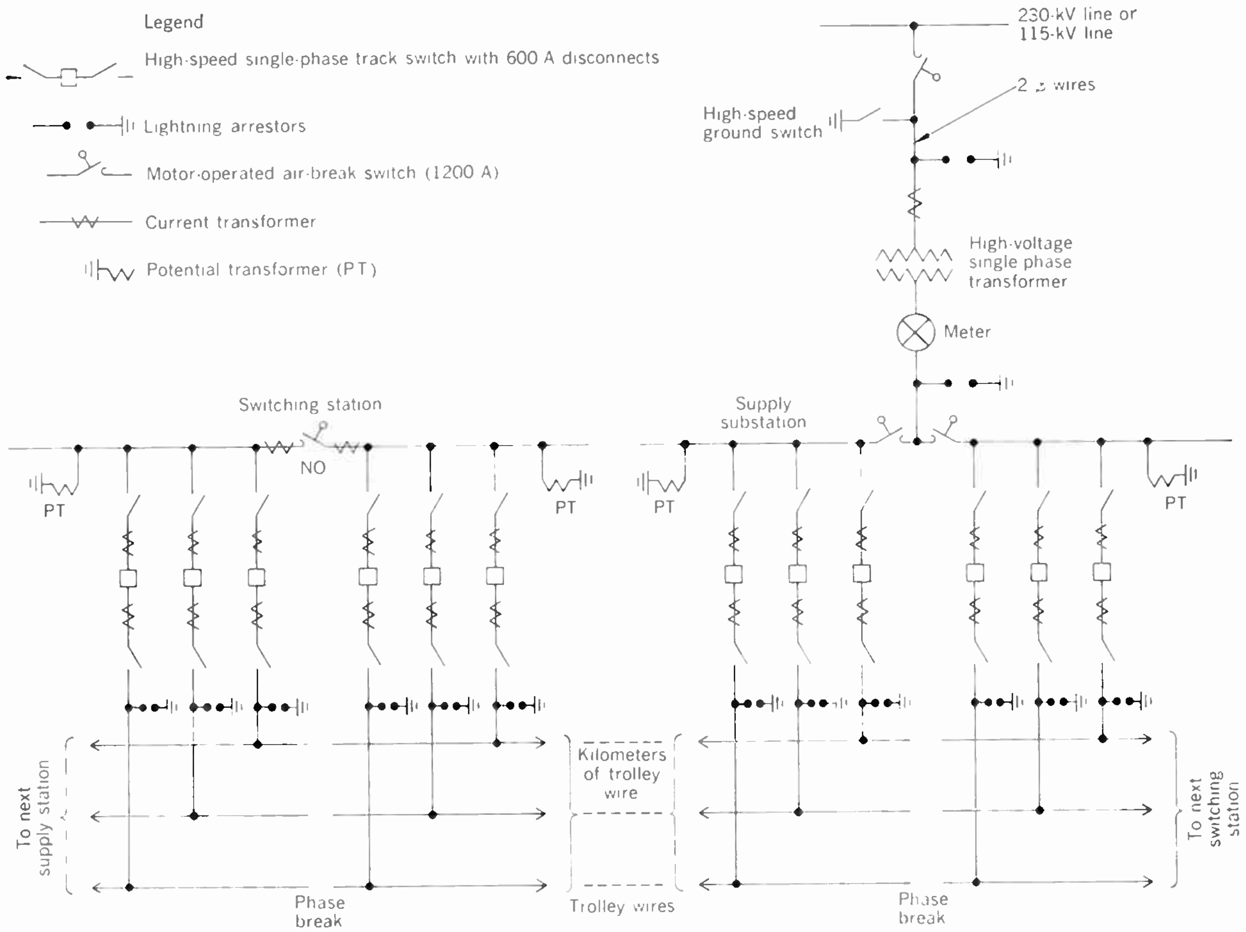


FIGURE 12. Proposed 25-kV, 60-Hz switching station and supply substation for Penn Central conversion.

average distance between supply points would be 32 km, on the assumption there would be a 10 percent normal voltage drop from the supply point to a pantograph at the end of a section. The scheme includes a center-feed system (Fig. 10), and a three- to six-phase transformer connection (Fig. 11). The proposed conversion would require 29 switching stations, which, together with the necessary supply substations, are shown in Fig. 12.

The Penn Central believes that the proposed conversion would markedly reduce electric energy rates and provide other economies in transmission line investment and maintenance. And the study by the utility companies indicates there would be no problem caused by three-phase current imbalance.

Rail rapid-transit schemes. Since this article deals primarily with interurban railroad systems, we will not attempt a discussion of the rail rapid transit lines that are being planned or built in numerous major cities throughout the United States. This vital area, and many other remarkable modes of high-speed transportation, is fully presented in the "Special Issue on Transportation," PROCEEDINGS OF THE IEEE, April 1968. This superb compendium is recommended reading.

Prelude to Part III

The final installment of this series (September issue) will take up the development of the great network of electrified railway systems in continental Europe and Great Britain, where different parameters in availability of hydro power, destructive effects of two World Wars, economic problems, and other factors present a different picture, in both the historical overview and future prospects, from that of the United States.

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Considerations in planning for reliable electric service

Applications of sound principles of planning, design, and operation—not revolutionary changes—are what is necessary to obtain satisfactory levels of reliability

Charles Concordia *General Electric Company*

To assure reliability of electric power, it is essential to have effective transmission and adequate interconnections, adherence to operating limitations, and recognition that, in spite of all that can be done, there is always the chance that an unforeseen contingency will cause system separation and possibly generator deficiency. The first consideration requires system studies to demonstrate that no single disturbance will cause cascading tripouts of lines or generators; the second may be facilitated by automatic monitoring of the system condition; the third requires automatic load shedding on low frequency.

This article is concerned with the reliability of bulk-power generation-transmission systems, which has been given special emphasis within the past few years. That is to say, it is concerned only with system design and operation to avoid widespread shutdown of the generation transmission system, even though by far the greater number of customer service interruptions originate locally in, and are confined to, the distribution system.

Although reliability is extremely important, and everybody seems to be in favor of more of it, there remains the question of what level of reliability is sufficiently high. A 100 percent availability of electric service can never be attainable, no matter how much time, effort, and money are spent, so it must be conceded that the objective is not 100 percent, but rather the maximum reliability that we can, and should, afford.

In most instances it is difficult, if not impossible, to put numerical values on the worth of continuity of service; and it has been the usual practice to strive for the highest level of reliability attainable with the state of the art, without questioning whether or not such a high level is really worthwhile. Work has been and is being done to evaluate the economic worth of reliability, but we do not believe that any electric utility would knowingly reduce its own standards even though an economic evaluation might appear to justify doing so. Instead, at present, all of the emphasis seems to be on increasing reliability.

As a result of the restriction of this article to the bulk-power generation transmission system, it may be interesting to estimate the level of generation-transmission system reliability that would be required to make the service interruptions caused by generation-transmission system outages an order of magnitude smaller than those caused by distribution system outages. In the full realization that we may not have accurate reliability statistics, we have assumed an overall average service interruption rate as small as one hour every five years, so that the interruptions caused by the generation-transmission system should then be no more than one hour every 50 years. Anticipating the application of the principles advocated in this article, this might, for example, correspond to a separation of each major system from the large interconnection of which it is a part every ten years, with a resulting loss of 20 percent of customer load. This is, in a way, an astonishing result, since the record may well show that present performance is already better than that required to meet such a standard.

In view of the present climate of opinion, we cannot conclude from this that there are no sound reasons for being at all concerned about generation-transmission system reliability. However, we can at least express the opinion that a satisfactory level of reliability is not so far off as to require revolutionary changes in practice. Instead, it can be achieved by strict adherence to the sound principles of design and operation that are already known and accepted by many utilities.

Design and operating principles

Principles that must be employed to achieve satisfactory service reliability can be summarized as follows:

1. Power systems must be designed so that, for any predicted future loads and system condition, the generation and transmission capacity will always be adequate to prevent any single incident from precipitating a second incident. This will prevent the first stage in what could develop into a cascading series of events and a split-up of the system. It does not appear necessary, or even possible in the general case, for the system to be designed to withstand multiple independent disturbances without any effect on service.

There has recently been a tendency at least to talk about using more severe design criteria than those based upon the worst single disturbance. Two comments may be made: first, and perhaps only incidentally, the use of multiple independent disturbances as a criterion cannot be justified by reference to events of the recent widespread, and widely discussed, power failures; second, there is a question of meaning and interpretation. For example, some persons call a tripout of a line that occurs when another line is already out for maintenance a double contingency. In this article, we shall try to avoid the words "contingency" and "outage," and speak only of disturbances. Thus the system condition to which we just referred includes those situations where lines (or generators) are out of service, or not available, because of maintenance, previous forced outages, delays in installation, or other causes.

2. Power systems must be operated within limits that will insure adequate pickup capacity to avoid cascading. This is evidently simply the converse of the first principle stated. Power system load grows more or less continuously, but transmission and generation equipment is added in finite steps, so that the operating margins are changing and the operating limits may alternate between generation and transmission.

If margins are sufficiently large, or if the system is sufficiently strong, only a few simple operating rules may be necessary to assure safe operation. However, it is uneconomical to add too much capacity too soon; hence, in many cases, continual monitoring of all pertinent factors may be necessary. Moreover, the increasing extent and complexity of system interconnections make it more and more difficult to keep track of all pertinent information. There is a proper balance between margin and surveillance, which should be carefully considered in appraising a system.

3. Regardless of how great the planned margins are in system design and operation, there is always the chance that they may be exceeded, either by a highly improbable combination of events, or simply by carelessness or error. Thus, as a final precaution, plans must be made to minimize the magnitude and duration of any resulting service interruption. These emergency procedures can and should be simple and drastic, rather than elaborate and precise, since, with proper system design, it can safely be assumed that something highly improbable and potentially catastrophic has occurred if there is a system split-up. In general, it is a major problem to preserve a balance between generation and load in areas that have separated from the main interconnected system. If this cannot be achieved in increasing generation, it must be achieved by dropping load.

These three principles are discussed in more detail in the following sections.

Design for adequate capacity

The process of system planning to determine a proper system design and the required transmission and generation capacity is very complex. (An excellent summary of the method is given in Appendix F of Ref. 1.) For the purpose of this article, however, it is only necessary to point out certain limited aspects. Planning is regarded here as a two-stage procedure.

First, the general system design is determined from preliminary load-flow studies. At the same time, a generation (and transmission) expansion plan is determined that will result in a system having an assigned quality of service reliability. This is measured in terms of a suitably high probability of having enough generation capacity available, within the area considered, to supply the forecast load. The calculation takes into account such factors as forecasting errors, maintenance schedules, and forced outage rates based on experience.

Next, individual systems are checked to insure that they can withstand the shock of specific disturbances, taking into account the network configuration, the operation of system protective equipment, control, and the effects of interconnection with other systems. Such dynamic performance checks are necessary to obtain a thorough understanding of system behavior and of the system design required to assure reliable service. Thus, they are mainly emphasized as a planning tool in this article.

It does not appear either feasible, necessary, or even desirable to test systems under all possible operating conditions for all possible disturbances. Instead, experience and engineering judgment must be used in selecting the most (reasonably) vulnerable system conditions and the most (reasonably) severe disturbances to test the system performance. Probability must be considered, at least in a qualitative sense. It would, of course, always be possible to assume a combination of disturbances that would induce collapse of the system. However, since this combination may have an extremely small probability of occurrence, it appears more useful to determine that the system will be able to survive intact (i.e., without consequent events that might lead to splitting up of the system) any single severe disturbance, such as a fault at the most critical location or a loss of the most important transmission line or of the largest generator. With the assurance that the system is indeed adequate to survive these disturbances, a more complete understanding of the system capabilities and behavior, as well as information concerning margins, can be obtained by increasing the severity of the disturbance. (A convenient and useful way of doing this is by the determination of critical switching time.) This will often uncover weaknesses in the system design that can then be corrected to minimize the spread of the disturbance.

On the other hand, even though the system can withstand a particular severe disturbance, certain milder disturbances are still of interest from the standpoint of reliability. For example, automatic reclosing is often studied and used, especially on generation-to-system transmission lines, in order to obtain better performance and quicker restoration of the system to a safer configuration for the more likely cases of temporary line faults. This is true, even though it makes the requirement that the system be able to withstand the loss of the line (in case of a permanent line fault and thus an unsuccessful reclosing) more severe.

Loss of line. Whenever a line is lost, the loading on the remaining lines that form a connection between the same two areas of the network will, in general, increase, since the same power must still flow through the network from the generators to the loads.

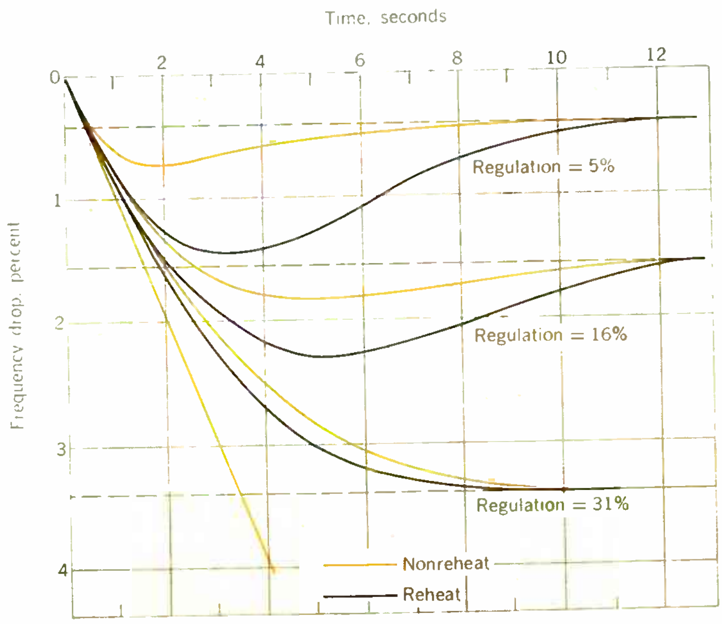
For example, if there were originally four equally loaded lines in parallel, the loss of any one of them would cause the loads on the remaining lines to increase by 33 percent on the average. These remaining lines must be able to carry this increased power stably and without initiating any further tripping of lines or other equipment. If a second line did trip, a further increase of 50 percent on the average would occur on the two remaining lines, which would now be carrying twice the original loading. It is evident that the situation becomes rapidly more severe, and that it is therefore necessary to prevent the possibility of cascading at the first step. Moreover, in the general case, the remaining lines will not share the increase in loading equally. In addition, they must withstand the shock of the power swing and overshoot that usually accompany a sudden change of line loading. The actual new loadings must be determined at the least by a detailed load flow, and, in apparently marginal cases, by a stability calculation,[2,3] taking account of all significant electrical, mechanical, and control parameters, and making sure not only that the system is stable but also that, even for a stable case, no apparent line or generator overloading will cause additional relay operations.

It is evident that a strong transmission network is a primary requirement for system reliability and flexibility in operation. There should be enough total transmission capacity so that the operator is relatively free to schedule generation as required and still maintain adequate pickup capacity over and above the resulting line loadings. These remarks apply, in general, to both internal and intersystem transmission lines, though not with equal force.

Loss of generation. Whenever a generator is lost, the generation loss will tend to be supplied, at least during the first several seconds, from all of the other generators remaining on the system more or less in proportion to their rotary inertias or speed-governing capabilities (or, very roughly, their ratings), regardless of their distances from the lost generator. Considering only one isolated system, it might, for example, be assumed that the lost generator was supplying 10 percent of the total system load. In this case, the generation of the remaining units would increase on the average by slightly more than 10 percent. By itself, this may not seem unreasonable, but it must be remembered that in order to pick up this amount of load automatically, in response to speed governor action, the system frequency would have to drop at least one hertz, and very probably more, depending on the distribution of generation among the units (see Fig. 1).[3] This frequency drop may not be tolerable, and at least is not desirable. The result can be a restriction of the permissible size of generators to a value considerably smaller than that found most economical from a probabilistic consideration of generation requirements to meet the load, an uneconomic increase in the amount of installed generation, or interconnection with neighboring systems.

The most usual decision in generation system design is to interconnect. Of course, interconnections have other advantages, and may have been accomplished for other reasons, such as the economic interchange of energy. When several power systems interconnect, they each become part of a much larger network, and their dynamic performance is changed radically. As an extreme example, in the eastern part of the United States the total network capacity is very great, and any one power system is only a small fraction of the total. In this case, when a generator is lost on any system, the amount of load that has to be picked up by any one of the remaining generators is almost negligible (less than 1 percent), and the resulting frequency drop is very small. As far as the deficient system is concerned, practically all of the generation that is lost will at first be supplied over the tie lines connecting it to its neighbors (Fig. 2).[5] This additional tie-line loading will occur within, at most, a few seconds, and will remain until automatic tie-line power control (possibly manual intervention) and, if necessary, the starting of additional units, have increased the generation in the control area.

FIGURE 1. Distribution effect on frequency from a 10 percent generation loss.



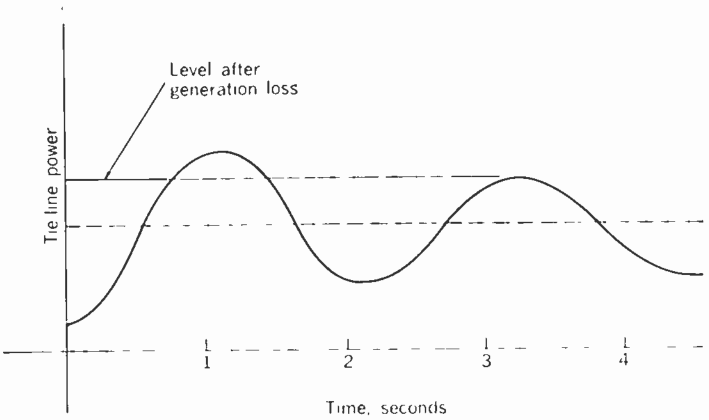


FIGURE 2. An example of a typical tie-line power swing following a loss of generation.

It is immediately evident that there is a very close relation between the strength of the ties and the permissible generator size, which is not related to the size of any one system, or of any pool, or of the total network, but to the pickup capacity of the tie lines.[5] The tie lines must have sufficient capacity to be able to pick up the additional load that might be suddenly imposed at any time by loss of the largest generator. This puts a lower limit on the tie-line capacity that should be installed, even if no energy interchange is planned. If the tie-line capacity is greater, the loading must be limited so that sufficient margin for pickup always remains. If the tie-line capacity is made still greater, the point may be reached where its permissible loading, on the basis of sufficient margin for pickup, can become greater than the largest generator. Then, loss of the largest generator may no longer be the most severe criterion. Instead, loss of one of the tie lines may become the limiting factor, and it must be checked to insure that the remaining ties do not trip out. The tie lines become, in effect, a new largest generator.

This discussion has shown that, to understand the dynamic performance of interconnected power systems, one must consider essentially the whole network. One does not have the freedom to choose an area for study, disregarding the rest. This consideration does not, of course, have to be in detail, but at the least the overall generating capacity, inertia, and speed-governing characteristics have to be estimated.[2,3] It may even be found that the largest generator or the most critical lines, from the point of view of a particular system, may be in one of the other systems to which it is connected. It is thus evident that there must be coordination of planning, or at least interchange of information about plans, among systems that are neighbors electrically, whether or not they are members of a formal planning or operating group. Moreover, performance may have to be restudied and re-evaluated on the basis of changed conditions in neighboring systems, including transmission, interconnections, generation, and relaying, as well as operating practices.

It can further be noted that the load that must be picked up by the tie lines when a generator is lost cannot be significantly reduced by increasing spinning reserve. By the same token, it will not be appreciably increased if reserve is reduced. This does not, however, mean that reserve is of no value, since it is essential in order to restore the scheduled tie-line loading as quickly as possible so as to return to a safe operating condition—that is, a condition that satisfies the assigned criteria of reliability.

We have spoken here of the beneficial effects of a large interconnection. It may seem that, after a certain size is reached, making the interconnection larger may not lead to any further improvement. However, experience indicates that the problem of providing adequate tie-line capacity can become more difficult for systems at the periphery of an interconnected network than for those in the interior. Thus, systems at the periphery may find it desirable from their own standpoint to interconnect in more than one direction. In other words, each system might like to be at the center of its own universe, even though it might not need that universe to be infinitely large.

Finally, we have discussed the benefits of adequate interconnection largely from the standpoint of the necessary redistribution of the flow of active power following a disturbance. Unfortunately, the same benefits cannot be claimed from the standpoint of reactive power. Reactive power cannot be transported around the network with the same freedom as active power. Instead, it must be to a considerable extent locally generated, and provision must be made for adequate capacity in this regard.

We can very roughly summarize this discussion of required system capacity as follows:

1. Keep up to date on plans, practices, and changes in neighboring systems.

2. Coordinate planning and planning studies in as large an area as necessary.

3. Know the most severe disturbance that the system can survive without splitting, recognizing that this disturbance may originate in some other system.

4. In system studies, consider all probable relay action [i.e., that arising from generator (reactive power) overloads as well as transmission line (active power) overloads] and not just the inherent dynamic limits.

5. Provide both an internal and an interconnection transmission capacity that is adequate to avoid cascading line (or generator) tripouts following any single disturbance for all reasonably foreseeable operating conditions. In those rare cases where an adequate interconnection is not feasible, no interconnection at all may be better than one that is too weak.

Operating limits

It must somehow be assured that the system is operated within the planned limits. The amount of information, as well as the frequency of checking this information, necessary to accomplish this depends on the design margin, particularly that of the transmission system. At one extreme, if the network is sufficiently strong, operation will almost inherently be within safe limits, so that very little monitoring should be needed. At the other extreme, continual monitoring of all information cannot make a weak network reliable. For economic reasons, the practical case lies between these two extremes.

It is necessary to have obtained a good understanding of system behavior from performance studies in order to decide on the significance and relative importance of the vast amount of system data that might be made available. Too much data can be of little use and even confusing if the corresponding limits are not known and if the implications of any steps that might be taken to avoid encroaching on these limits are not clearly understood.

It thus seems desirable to discriminate among the data with respect to the frequency and detail of monitoring. On the other hand, some degree of information about the whole interconnection is necessary. Such information is pertinent because the condition of neighboring systems directly affects the behavior, and thus the reliability, of one's own system. For example, unplanned outages in some neighboring system may reduce operating limits or require changes in the allocation of generation of both active and reactive power, power interchanges, generation reserve, transmission, intersystem ties, and relaying. In other words, a pre-emergency situation may arise solely from external causes. This may necessitate operating without adequate reliability for a short time, but with the readiness to take special emergency action if a disturbance occurs on either system. Conversely, there is an obligation to inform one's neighbors of special system or equipment conditions that might require them to take similar precautions. In summary,

1. One should decide upon operating limits and stay within them.

2. Rules of thumb are much better than no rules (and, in many cases, may be entirely adequate), but performance can be improved by recognizing that limits are not always simple constants but may be affected by many factors, both internal and external.

3. As in the case of planning, coordination and exchange of information among interconnected systems are essential.

System split-up

By now, it should have become evident that we take it almost for granted that a power system cannot practically achieve the degree of reliability being discussed (even though it has not yet been exactly defined), except by becoming part of a relatively large interconnection. Thus, when a highly improbable disturbance, much more severe than the disturbances selected as design criteria, does occur, its effects most often split the system at generally unpredictable points. This may leave some of the isolated areas in danger of imminent collapse, because of insufficient generation to serve the connected load, especially since one or more generators may have been lost during the disturbance. In this case, some of the load must be disconnected in order to save the rest. Of course, the remaining generators will pick up load within their capacities as a result of speed-governor action responding to the drop in frequency. Unfortunately, however, there is sufficient time delay in governor action that for the first one or two seconds it is practically impossible to tell whether or not the system will recover. Moreover, even if it did, it would be left at a low frequency. This might cause an eventual decrease in generating capacity and, in any event, would persist and thus prevent the possibility of rejoining the network until frequency was restored either by adding new generation or reducing load. In view of all factors, especially the presumed low probability of the event, when the frequency suddenly drops it would seem advisable to shed load immediately and automatically.

What is the minimum amount and optimum location of the load that must be shed? In order to determine this exactly, information regarding loads, generation, and line loadings from all over the area would be required. However, at a time of major disturbance from (probably) unknown causes, and with the prospect of imminent system collapse, it does not seem prudent to take the time and trouble to calculate precisely the least that needs to be done, nor to depend on the correct operation of communication facilities, quite aside from the expense and additional complexity involved in acquiring and maintaining such facilities. Instead, it seems much more sensible to depend simply on the frequency already available locally at every load point, and which is the surest indication of insufficient generation.

An indirect and very rough measure of the minimum amount of load that should be shed as a first step can be obtained from the size of the largest generator or the pickup capacity of the interconnecting tie lines, in conjunction with the normal amount and distribution of reserve. Ten percent has been chosen by some companies.

The exact value of frequency at which this first step of load shedding should operate is not critical, since as long as the total interconnection is intact, frequency deviations of more than 0.2 Hz are very unlikely. Every reasonable chance must be given for the speed governors to call upon reserve, and a margin must be provided for violent system swings. In view of these considerations, a frequency of 59.3 Hz (or a frequency drop of 0.7 Hz) has been suggested, and seems very reasonable.

Because of relay and current-breaker operating times, the frequency will continue to drop below 59.3 Hz before the load is actually removed. Even if the 10 percent load block is enough to restore frequency, the frequency may drop 0.2 or 0.3 Hz more, to perhaps 59.0 Hz, before recovering. If frequency continues to drop further, a second load block should be shed at, for example, 58.9 Hz. The second step should be at least as great as the first, and load shedding should continue in steps at least as large until frequency is restored. That is, there is no valid reason to stop the process until most of the load is shed, as it seems better to preserve even a small amount of load than to lose it all, and since an orderly reduction of load leaves the remaining generation running and thus immediately available to restore service.

It has often been pointed out that there are many essential loads, especially in or near large cities, that must not be shed. This can easily be said now, but as time goes on more and more areas will become urban, and more and more loads will become essential, so it may become impractical to consider all such loads as special cases.

Because of the system oscillations that usually accompany a disturbance, the frequency is not the same at every load point (see Fig. 3), so there may be a certain amount of randomness in the order of underfrequency relay operation. One may therefore wonder why load should necessarily be shed in steps. The principal reason is to insure that the loads that are shed at each step are at a sufficiently large number of points widely distributed around the system that any increases in line loadings are unlikely. This brings up the point that, since the boundaries of the isolated area will not necessarily coincide with the boundaries of particular companies, more than one company may be involved in the area. Then it becomes evident that an adequate load-shedding program requires that neighboring systems also have one.

Perhaps the most important thing to say about load

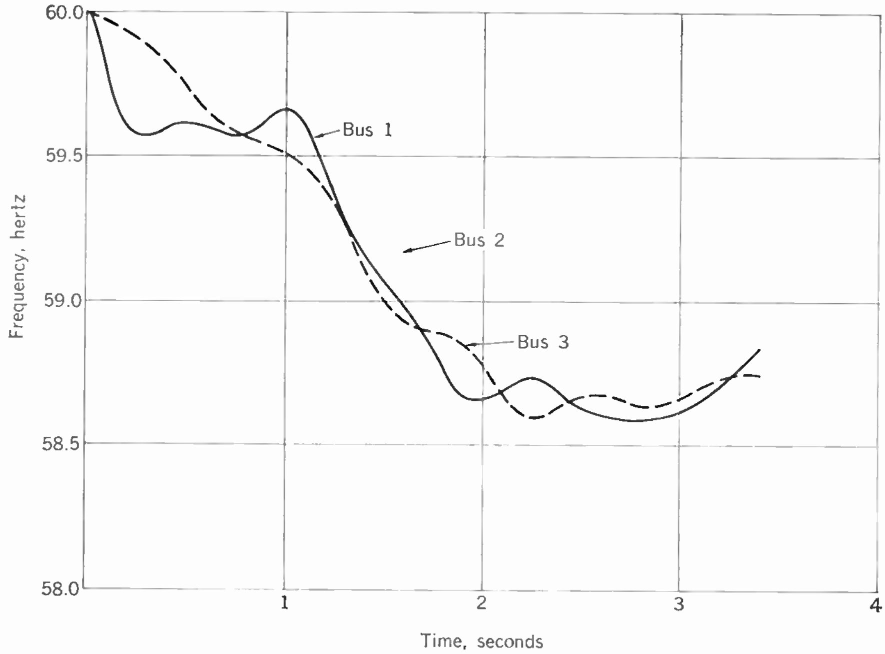


FIGURE 3. Time–frequency characteristic of a system after a 10 percent loss in generation. The load shed is equal to two thirds of the generation loss at approximately two seconds.

shedding is that one should not consider it in the system or equipment design. That is, one should not use it as an excuse to reduce the requirements of transmission pickup capacity or of generation response. It is a backup procedure that, with good fortune, may never be used.

Generation response for a given amount of reserve can often be improved by distributing the reserve somewhat more uniformly over the system than would be indicated by a purely economic allocation. It can also be improved by making sure that controls are properly adjusted to avoid restricting rates of response to values below those inherently imposed by the unit thermal stress limits. The frequency drop required to cause an increase in generation of more than 15 or 20 percent purely by speed-governor action would be intolerable anyway.

An isolated area may, of course, have *excess* generation. Ordinarily this is no problem, as speed-governor action will limit the frequency. Cases requiring special consideration may occur when the generation is several times the load, and, in a different form, when a large fraction of this generation is hydraulic-turbine driven.

This discussion of emergency procedures (which became principally a discussion of automatic load shedding) can be summarized as follows:

1. Making sure that the system is always in a position to withstand any reasonable disturbance is only half the job. Consider what must be done if a much more severe incident occurs.

2. Implement these plans automatically so far as possible. For example, automatic load shedding as a response to low frequency should be universally applied.

Concluding remarks

There is a very long list of items that have not been discussed in this article. Our approach has been, in general, not to discuss any subject about which we believe there is practically universal agreement. These include equipment reliability, inspection, and maintenance; planning of installed generation on a probabilistic basis; forecasting of future loads; analyses of outages; and provision of restarting means.

Other subjects, such as special means to improve stability, precautions in restarting a system, provision of local emergency supply for loads regarded as critical, and many special situations, have not been discussed, since we have regarded them as not within the article's scope (although we believe there is much that can be learned about restarting).

In the hope that no statement has been made that does not seem obvious, we reiterate our opinion that a satisfactory level of reliability can be achieved without revolutionary changes, but merely by strict adherence to sound principles of planning, design, and operation that are already known and practiced by many utilities.

Essentially full text of a paper presented at the American Power Conference, Chicago, Ill., April 23–25, 1968. This paper will also appear in the *Proceedings* of that conference.

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International communications: the problems of progress

Now that satellites are up and working, the main problems in international communications will involve achieving a balance between satellites, cables, and other systems that will provide capability, reliability, and economy

T. B. Westfall
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Many people think that the future of international communications lies only in the expansion and refinement of satellite facilities. However, cable and radio continue to play vital roles in the overall telecommunications picture. In the long run, the resultant mix of satellites, cables, and other forms of communication will be determined by what each form does best—and at what cost.

Authors dealing with international communications frequently paint glowing pictures of miracles that lie just around the corner, thanks to science in general and communications in particular. The problems are usually ignored.

This sort of thing can win a man a reputation as a prophet, if his audience lives long enough. But it isn't very helpful to international communication managers, whose job is to perform minor miracles of communication daily with budgets that seldom match the objectives they are expected to attain. Each time they spend a dollar, they need to know the problems as well as the promises of progress. So I shall focus my discussion on some practical considerations that are going to affect the direction and rate of progress in communications over the next few years.

To begin with satellites: The spectacular advances made by satellite communications are witness to a host of problems that already have been overcome. Those problems have involved politics, finance, diplomacy, law, administration, and salesmanship, no less than research and engineering. Everyone in the industry recognizes the superlative job that the Communications Satellite Corporation (Comsat) has done in solving problems to date. As a member of the Comsat Board of Directors, I welcome this opportunity to pay public tribute to the management of that company for getting the satellite system up and working.

But it would be remiss to give the impression that the problems of satellite communication have all been solved. To judge correctly the future of satellites in communications, one must know at least what the more important of those problems are. High on the list is the relationship between satellite and other forms of communication.

Judging from newspapers, a lot of people think that communications progress came to an end when satellites were invented. Or, if they admit the possibility of further progress, they assume it will be limited to satellites. The International Telecommunication Union probably contributed to this view when it published its recent centennial volume under the title, "From Semaphore to Satellite." And Comsat itself may have unwittingly encouraged the misapprehension in its eagerness to promote the only product it has to sell.

The 'death' of cables

Businessmen will question on principle the wisdom of putting all their eggs in one basket. History supports them. Not long ago, I was given a reproduction of the front page of *The San Francisco Call*, with a headline reading "Death Knell of Ocean Cable Is Rung." There have been a lot of headlines like this since Early Bird's inaugural in 1965. But this one had nothing to do with Early Bird. It appeared on July 29, 1912, and the event it featured was the first spanning of the Pacific, from San Francisco to Honolulu, by the Poulsen radio system pioneered by Federal Telegraph Company, a predecessor of ITT World Communications.

Everything the radio enthusiasts predicted in 1912 has since come true, with one exception: the cables have

This article is adapted from a speech delivered before the International Communications Association, Philadelphia, Pa., May 6, 1968.

not died. They have not died because they had then, and still have, certain unique advantages that radio cannot match. They have also shared with radio many of the basic engineering advances of our time.

This combination of unique advantages and common access to modern technology is also keeping very much alive some older forms of radio that many people thought were dead or dying. For example, low-frequency radio is still employed by the U.S. Navy to communicate with submarines cruising beneath the surface of the ocean—basically because no other technique is equally effective.

A new lease on life for HF radio

As a further example, the recent development of LINCOMPEX (linked compressor expander) has probably saved high-frequency radio from the grave that satellite enthusiasts had prematurely dug for it. Anyone who has not yet talked on a high-frequency LINCOMPEX circuit, several of which are now in operation between the United States and South America, should make it a point to do so. He will find the quality of his conversation hard to distinguish from any he has had over a coaxial cable, and he will be relieved to find no trace of the delay that annoys him when using satellites. Were it not that the system is limited to voice and to the entirely inadequate capacity of the HF radio spectrum, both coaxial cables and satellites would be in for a rough time, because HF LINCOMPEX is so much cheaper than either of them. In any event, we may predict a long and healthy life for the HF radio corpse—as revived by LINCOMPEX.

Because each form of communication has special excellences that the others cannot match, each has a firm base of operations from which to compete with the others in borderline areas. Also, from time to time, each will secure a technological jump on the other, and so carry on into the future the game of leapfrog that has characterized the past.

The original transatlantic cables—with their limited number of channels, capable of providing only telegraph communication and at very slow speeds—held the stage from 1865 until radio made its appearance early in the present century. The newcomer, radio, was far cheaper than the older cables and, in addition, could offer transatlantic telephone service for the first time.

Satellites and the RF spectrum

Radio had problems of its own, however—most notably, a frequency spectrum too limited to handle very long the increasing demands upon it. On land, utilization of microwave frequencies afforded some relief wherever it was practicable to erect towers to relay its line-of-sight transmissions. But not until the appearance of satellites was it possible to transmit microwaves across the oceans.

Satellites, however, cannot cure the problem of the limited frequency spectrum that afflicts microwave radio as surely as it does HF radio, although not to the same degree. Moreover, satellites introduce two further major weaknesses of their own: those of "parking space" and time delay. To assess the future of satellite communications, let us consider each of these problems.

First, the limited frequency spectrum. Microwave transmission at 10 GHz and above is subject to both attenuation and scatter by rain, snow, fog, smog, and dust storms. The problem of attenuation might be solved by building several alternative ground stations several hundred miles apart. But the expense of that solution would cripple the ability of satellites to compete on economic grounds with other forms of communication. The scatter effect, for its part, could result in interference with other microwave services on earth, and so is equally inadmissible.

The problem of parking space is one associated with our present system of geosynchronous satellites in equatorial orbit 35 800 km (22 300 miles) above earth. Because these satellites are able to relay messages only between earth stations that they can "see," parking space for the satellites needed to serve areas of greatest demand is at a premium. Even if the present requirement for one degree of separation between satellites should be reduced to one tenth of one degree, available parking space would still fall short of what would be necessary to provide economically the national and regional networks, educational networks, military networks, and all the others now being proposed in addition to the international network we are building.

The third limitation of satellites—that of time delay—is the most serious of all, because the only cure for it would seem to be a change in the 300 000-km/s speed of light. One 72 000-km round trip from earth to satellite and back produces a quarter-second delay, which can be tolerated by the human ear but creates problems for certain data systems under present technology. However, a single hop cannot carry traffic halfway around the world. For that, two hops are necessary, and the resulting half-second delay is totally unacceptable to the ear and intensifies the problem of data systems.

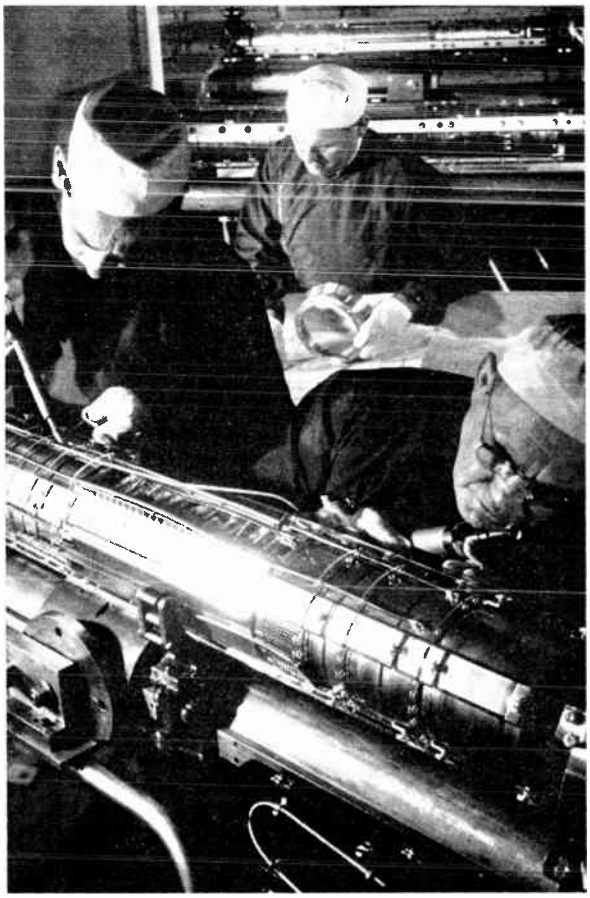
Cables have problems, too

Although the original telegraph cables continued in service long after the introduction of radio early in this century, they did so mainly because of their durability and the fact that their cost had in most cases been written off. It was not until the development of submarine coaxial cables, which could carry voice and were immune to the fading and frequency problems of radio, that cables got back into the competitive picture.

The principal shortcomings of submarine coaxial cables, when they made their bow in the 1950s, were their cost and their limited channel capacity. But as successive cables were built, their capacity was increased and their cost per circuit mile was reduced. The first transatlantic telephone cables—TAT-1 and TAT-2—and the first such cable between the U.S. mainland and Puerto Rico, were dual cables that yielded only 48 channels together. The cable that is being laid this summer from Florida to the Virgin Islands, and the TAT-5 cable planned for the Atlantic in 1970, provide 720 channels over a single cable; these can be increased from 80 to 90 percent for voice by using TASI.

Laboratory development of a 1540-channel cable will be completed next year, and 3000-channel cables will be available three or four years after that. Because of this increasing capacity and a 20-year life in which to write off costs, the modern submarine coaxial cable is and will remain fully competitive in price with anything that satellite communication can offer, even when the projected 5000–6000-channel Intelsat IV series of satellites goes into operation in the 1970s.

Latest calculations in connection with the TAT-5



SUBMARINE CABLE communication, exemplified here by the manufacture of transistorized submarine repeaters in London, has made great progress since the time of Cyrus Field.

cable indicate operational and maintenance costs as being substantially less than the $3800 monthly it now costs to lease a satellite channel from Comsat.

The charge has been made that because of the traffic it will divert from satellites, the TAT-5 cable will keep satellite costs higher than would otherwise be the case. Even if this were true, consumers would find it hard to understand why they should be debarred from the cheaper cables in order to make life easier for satellites. But the charge is not true. What keeps satellite costs up is the fact that, in order to meet increasing demands for service, one of two steps is required (and both of them are expensive).

The first is to put into orbit more satellites of the current model, which would be relatively cheap and permit those already there to be written off over their normal life span. To duplicate the satellites, however, you must duplicate the earth stations—a very expensive procedure. The alternative approach is to write off existing satellites at an accelerated rate and replace them with newer, and more expensive, satellites of larger capacity. Cables do not present this problem; if additional capacity is needed, you simply add another cable and continue to use—and write off normally—the ones already there.

The issue between cables and satellites was squarely faced last fall, when the U.S. carriers requested permission of the Federal Communications Commission to join with several European administrations to lay the TAT-5 cable. The FCC granted its permission in February of this year to file application to lay such a cable, subject to three principal conditions: completion of the project by early 1970, reduction of rates, and proportional fill of TAT-5 and the satellite serving the area.

As an interim solution, this Judgment of Solomon has undoubted merit. But in the long run, the factor determining the future mix of satellite, cable, and other forms of communication will be the test of what each does best, and at what cost.

Cables versus satellites

Satellites can do a number of things that cables cannot, and they can do a number of other things better or more cheaply than cables. These include navigation and traffic control; communications with airplanes, earth vehicles, and ships at sea; communications over vast expanses of water or little-developed land masses; and the distribution of audio and television programs to sparsely populated regions. The limited frequencies and parking space available to satellites should, therefore, be used primarily for these services.

In the same way, cables should be used primarily for services they can provide better than satellites. For example, all traffic destined for points farther than one satellite can take it will have to be carried beyond those limits by cables or other earthbound systems, owing to the time-delay factor that precludes two-hop satellite service. Regional and domestic satellite systems cannot be linked to international satellite systems, or vice versa; cables at one end or the other will solve the problem. Cables will also provide the answer wherever traffic exceeds the capacity of radio frequencies to carry it. Someone has already remarked that you could pave the ocean floor with cables using the same frequency, without mutual interference. On land, cables are likewise the indicated means of handling unlimited demands for traffic—at least until such time as waveguides and laser guides are ready to take over.

It is evident that cables, satellites, and some of the older forms of radio communication will be with us for a long time. This is no less important to the customers than it is to the carriers, and for the same reason: Dependability of service is in direct proportion to the number of alternate routes and techniques available. Cables can be cut and satellites jammed. Even without jamming, satellites are as vulnerable to outages as cables.

A study of the two systems across the Atlantic from January 1 through July 31, 1967, yielded these figures: for all cables, from cable head to cable head, 99.9 percent reliability; for Early Bird, from ground station to bird to ground station, 99.3 percent; for all channels employing cables, from customer to customer, 99 percent; for all channels employing the satellite, from customer to customer, 98 percent.

Combining systems

For customers and common carriers alike, the point is not that either system is better than the other but that neither system is perfect. Therefore, the presence of the two makes it easier to ride out failures in either one.

That is why the cable Hot Line between Washington and Moscow has radio backup. That is why a system employing many cables is better than one employing a single satellite, no matter how sophisticated the satellite may be. And, in the unlikely event that the satellite and all the cables should go out together, communicators would be very glad to fall back on high-frequency radio—with or without LINCOMPEX.

Other areas of potential progress

A brief review of several other areas of potential progress, and some of the problems that need to be solved before those potentials can be fully realized, is in order.

Some of the most troublesome problems have to do with economics. Not even our affluent U.S. society can afford to write off millions of dollars worth of long-line installations to meet the channel requirements of Rectiplex, which is capable of providing 108 telegraph channels instead of the usual 22 for each 3 kHz of bandwidth, over landlines that are free of phase perturbation. Such landlines have been unobtainable in the United States until this year.

For many of the underdeveloped nations the benefits of satellite communication are going to be small indeed until these countries build at least a rudimentary domestic network to serve their people as a whole.

The solution of these problems will require time, patience, and money—all of which seem to be scarce these days. If nationalism were less, private enterprise could help far more than it is being given the opportunity to do. Because of nationalism, progress will be needlessly slowed to the bureaucratic pace of socialism in many parts of the world.

There is another group of services available, whose application is being held up either because of slowness of market development, or failure of the law to keep pace with commercial need, or conflicts of interest that raise issues not yet solved.

One example is facsimile. It is now possible to print entire newspapers at virtually any distance by facsimile transmission from a single source. *The Wall Street Journal* is using this means to print its Western edition, and I understand that some London newspapers do the same with their provincial editions. Last summer ITT World Communications proved that the same thing can be done internationally, by arranging for the transmission of the front page of the *London Daily Express* to Puerto Rico on the occasion of the Inter-American Press Association meeting there. But the market for this technique will remain unprofitably small until mergers in the publishing field create a demand that does not now exist.

Facsimile transmission

The application of facsimile to the transmittal of legal documents awaits the sanction of the law in many cases. As an example, consider the problems involved on the last scheduled day in port for a freighter when the docks are jammed with last-minute shipments that must be checked and painstakingly entered by hand on bills of lading that have to be signed in triplicate and affixed to each item before the ship sails. If those documents could be completed after the ship left port, and forwarded by facsimile, a major headache would be relieved. A similar problem exists when ships unload and the bills of lading are found to be defective; in this case, facsimile transmission of the corrected documents could save thousands of dollars. To make this possible, the shipping interests must apply pressure to effect the necessary modification of the law.

For companies large enough to warrant computerizing their document files, international access to such files by telex, coupled with facsimile transmission of the particular documents required, could save days for high-priced men in the field. An approach to this was demonstrated by us last summer in cooperation with Radio Suisse and Italcable, for the World Peace Through Law convention in Geneva, Switzerland, and the Italian Magistrates and Jurists convention in Campione, Italy. Delegates were able, by means of telex, to query the computerized library of Law Research Associates in New York and get their case citations back by telex in seconds. Addition of facsimile would have permitted transmission of entire cases page by page within minutes—at the cost of a 48-kHz channel. In a similar demonstration for the medical profession, heart and other vital data were transmitted from a soldier in a hospital in Japan to Houston, Texas, for diagnosis. In these applications the limiting factor is cost, not law.

Computer inquiry

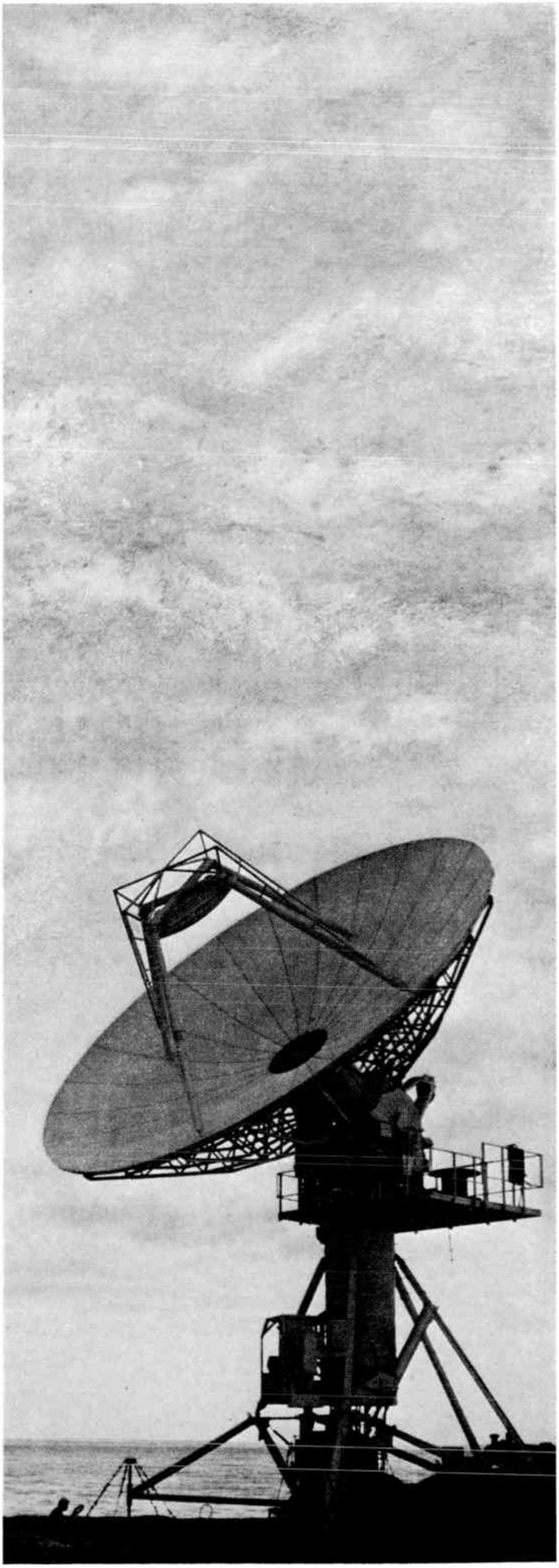
A recent newspaper article reported dissatisfaction among weathermen with the advances in long-range forecasting so far realized from the pictures of global cloud cover being received from weather satellites. If the article was correct, what seems to be missing is the additional and simultaneous transmission of vital ground information as well—from 150 selected spots around the globe. But that, it was pointed out, would require a computer at each of the 150 locations—which, at $5 million a computer, involves simply too much money to contemplate for this purpose at this time. Even if money were no problem, the conditions under which U.S. carriers might participate in such a network would not be known until the conclusion of the computer inquiry now before the FCC.

The FCC has already acted in another important field, as a result of customer needs and the competition of U.S. record carriers to meet them. It has sanctioned customer derivation in international service of up to 22 channels over cables and up to 24 over satellites. This service is now available between overseas points where U.S. record carriers or their affiliates operate at both ends of cable or satellite circuits. Pending decisions at forthcoming regional telecommunication conferences, many government administrations overseas have indicated a willingness to permit customer derivation on a limited basis, such as one data channel and three telegraph channels. They are willing to consider customer requests for greater channel derivation on a case-by-case basis. We are hopeful that most overseas administrations will in due course accord customers the right of full channel derivation.

Marine telex

The fact that international communication always involves two ends of a circuit means that a latent problem in almost every area is negotiating the agreement of the corresponding government entity. One of the

COMMUNICATIONS by satellite is typified by ITT portable satellite ground station.



few exceptions is marine communication, where ship-to-shore telex is gaining steadily. A major hurdle was the seemingly logical assumption that the present level of marine telegraph could not possibly warrant putting a teleprinter on shipboard. What this assumption overlooked, of course, was the volume of traffic that *would* exist if a teleprinter were aboard. By connecting ships through telex with shore-based computers, it is possible to have all the advantages of a computer on each ship, including the whole range of telemetering that would save days of time in port. In addition, marine telex can facilitate new activities, such as offshore exploration for oil and the monitoring of deep-sea diving.

The question of merger

No discussion of progress in international communications, and the problems thereof, would be complete without a word on the question of merging the U.S. record carriers, with or without Comsat and the Long Lines Division of AT&T. This question has been more or less alive ever since the merger of the domestic telegraph system in the 1940s left the United States with a number of competing entities providing international service. Several studies have been made, including a recent one by the Stanford Research Institute. The problem was turned over last year to the President's Task Force on Communications Policy. President Johnson's announcement that he would neither seek nor accept nomination by his party for the forthcoming election preceded by several months the scheduled report by his Task Force. Politics in America being what it is, and merger being very much involved in politics, one cannot avoid the conclusion that further delays are inevitable.

Fortunately for the customer, the benefits of merger are no longer what they would have been 20 years ago, when competing radio and cable installations could seldom be justified on economic grounds. But today, with all carriers sharing common cable and satellite facilities to the extent their traffic warrants, this situation no longer obtains. And for the consumer, the benefits of competition remain very real—as witness the host of new services and lower rates that have been typical of communications in recent years.

Companies in international communications produce few miracles, but they do make steady progress—by solving problems that are as varied as life itself. These problems are more likely to be economic than technological. The carriers believe that their ability to provide fast, reliable service requires the development and use of every means of telecommunication available. The fact that the services offered today are better, more varied, and cheaper than they were a generation ago should help the advanced nations and also speed the development of those that still have far to go.

With the help of customers and the cooperation of the legal profession, the FCC, and foreign administrations, the carriers will continue to solve problems and improve their service with or without merger.

VITA—a

VITA, as a Latin word, means life; as a name it represents one of the most unusual voluntary services of contemporary times. Volunteers for International Technical Assistance fulfills an essential need in the field of foreign aid by supplying technical information to such groups as the Peace Corps,[1] The Agency for International Development, and the International Executive Service Corps (IESC).[2]

In the spring of 1959, a group of engineers and scientists, consisting mostly of men from General Electric and Union College, attended their regular luncheon meeting of the Mohawk Association of Scientists and Engineers (MASE). The men were discussing the international technical cooperation activities of the United States State Department and the United Nations. One of their prime concerns was the need for technical information.

They realized that a unique service was needed—a service to match technical knowledge to the needs of village missionaries, field service volunteers, government representatives, or local officials and businessmen. In short, a system was needed to apply the best available technical talent to the problems in underdeveloped countries, as defined by people working and living there, and as delineated by available local materials and technology. Finally, the solutions to the problems had to be cheap, efficient, and applicable, to enable people to help themselves without loss of pride.

Various MASE members did some quiet research before their next luncheon. When again they met it was discovered that the total of all the salaries for overseas manpower in the field of foreign service was about equal to that of the Schenectady area technical manpower pool alone. In the words of Benjamin P. Coe, VITA's executive director: "They began to add up how much of their spare time they might be able to give to a voluntary information service. It looked promising, so they started writing around to see if anybody could use this service, and it sort of grew from there."

The idea was simple—the organization was to be similar to a "postal Peace Corps." When a field worker, such as a missionary or Peace Corps Volunteer, needed technical information he would write to VITA, an appropriate expert would be selected, and a description of the problem would be mailed to him. Within a given

sociotechnical challenge for the IEEE

More than half of the world's population is in a technological limbo—willing and eager to better themselves; but lacking technical "know-how." The IEEE; through VITA; is in a unique position to help others, less fortunate, to help themselves

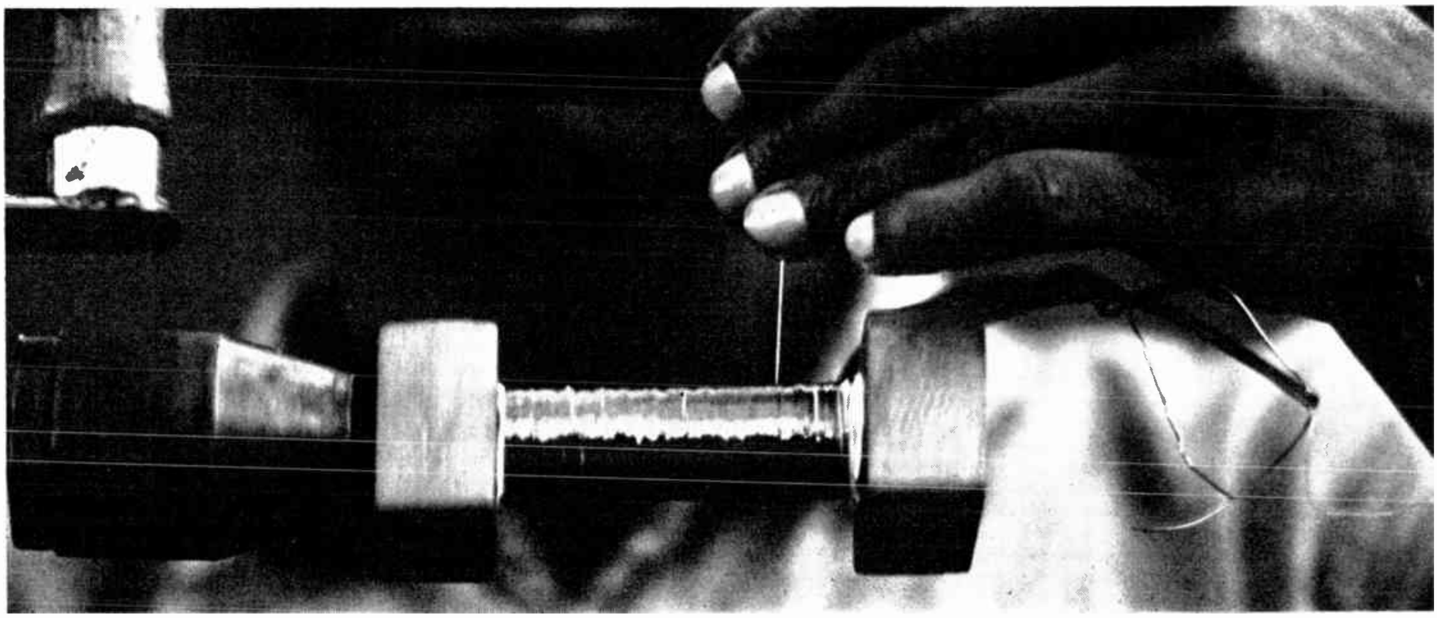
Harold L. Hoffman *Assistant Editor*

period of time the completed solution would be returned to VITA headquarters, and then forwarded to the requestor.

Twenty members of MASE, led by Dr. Robert M. Walker, a GE physicist, incorporated VITA in the State of New York in June 1960. In the words of Dr. Walker: "We had the capability of starting something in our own town that would help change the world. We were convinced that if we made a beginning others would join us; and that we must at least apply whatever knowledge we have to the task."[3]

VITA's first problem was a simple one, but it was a start: some priests of the Maryknoll Fathers in Latin America wanted to show educational filmstrips in an area without electricity. The problem was forwarded to minerologist Robert DeVries, who devised a simple adapter made of wood, bamboo, sheet plastic, or construction paper that would enable them to show filmstrips with a battery-powered slide projector.

Many of VITA's problems today, of course, are far more sophisticated. A doctor in a missionary field hospital is being transferred from an area with a 220-volt, 60-Hz power supply to a country with a 120-volt, 50-Hz main. What, if anything, must be done to convert his



X-ray machine for use in the new area? A Peace Corps Volunteer is working with a fairly sizable, though remotely located, local power cooperative. He needs to know how to synchronize their generating plants to keep them all in phase, and if the job can be done with solid-state devices.

In the limelight

As word of VITA's effectiveness spread among the various field volunteers, the number of requests grew in both volume and complexity. The need for a full-time, paid office staff was pressing, as the volume of requests and answers was becoming overwhelming. Benjamin Coe, at GE, took a leave of absence to assume directorship of the new staff. VITA remained strictly local, however, until 1964, with no fund-raising campaigns or income other than donations from volunteers and "a couple of science foundations."

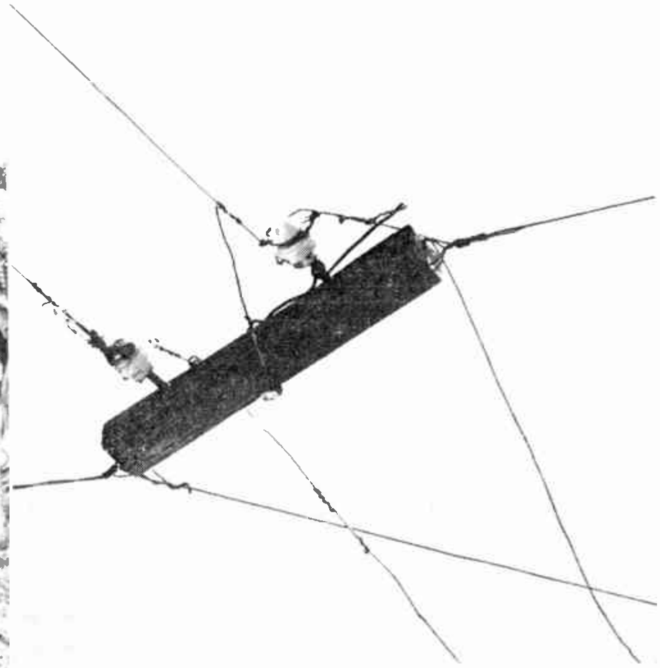
In 1965 things changed; an article on VITA appeared in the *Reader's Digest*, and the response was phenomenal. Between October 1, 1965, and May 15, 1966, 600 responses from volunteers, which were directly attributable to the article, were received at VITA's headquarters at Schenectady; 315 were from the United States, 285 from other countries. Of 759 requests for technical information received during the same period, 208 were from persons reading about VITA in the *Reader's Digest*.

The enthusiasm evoked by the article was welcome; but its suddenness generated a few problems. For example, as a direct result, international correspondence increased to the point where VITA had to institute a translation service capable of handling Spanish, German, French, Chinese, and Turkish.

VITA today: the need to know

VITA's basic reason for existing is to answer requests for technical help from people in underdeveloped countries who are trying to improve their basic living conditions. This activity does not include, as with some other agencies, sending sophisticated machinery, instruments, and techniques to areas that are often incapable of using them. VITA supplies practical technical engineering information that will enable people to build their own simple equipment from the resources that are available in the area.

More than 12 000 requests for technical information have been processed from 120 countries. Some 5300 voluntary members, from all 50 states of the United States and 63 other countries, donate their spare time from holidays, weekends, and evenings toward answering the requests. The membership is made up of scientists, educators, businessmen, technicians, engineers, and other specialists who are associated with 800 corporations and



200 universities, agencies, and institutions as either active or retired personnel. Volunteer membership is growing at the rate of 30 percent per year. Many scientific and engineering societies endorse, and even promote, involvement of their members with the program.

Among others, VITA assists the United Nations, the Peace Corps, CARE, Catholic Relief Services, American Friends Service Committee, Church World Services, the Agency for International Development, the International Executive Service Corps, and various missionary groups. In addition, VITA corresponds directly with individual citizens, as well as with governments in underdeveloped lands. VITA's inquiry service is free to anyone; and the only qualifications to be met are the need and the desire to *know*.

The foundations of VITA rest on supplying information with person-to-person guidance. The success of the entire idea was based on the assumption that scientists, engineers, and other specialists from private industry would welcome the chance to make personal contributions to world progress and peace by helping people in backward or deprived areas of the world. The group's faith in human nature was substantiated. At present there are 15 local chapters in the United States and one in Canada. In each chapter the volunteers apply their knowledge, freely given, to solving problems of "intermediate technology" in every specialty and discipline of our age.

A problem, the know-how, and a three-way approach

The heart of VITA's services is its ability to mate a problem to be solved with the volunteer who has the know-how. The organization originated as a person-to-person inquiry service, and this remains its primary function. When an inquiry received at the main office is to be handled by personal correspondence, the problem is assigned a classification as to category, information on hand, etc., and listed in numerical order for the records file. By means of a cross-indexing card file, the names of available volunteers, previously assigned a similar code number, are retrieved. Copies of the problem are sent to three volunteers, along with a deadline for receiving a reply. After the solutions are received at headquarters they are reviewed, either by members of the staff or other volunteers, for practical usability and then forwarded to the requestor. Usually the volunteers and requestors exchange private correspondence to obtain additional information and feedback; this procedure insures a more effective program.

As the volume of requests grew, it became obvious that the person-to-person approach alone was not enough. This realization, coupled with large numbers of requests that were similar, prompted VITA to initiate a publications program. First of the series was the *Village Technology Handbook*, compiled and published by VITA for the Agency for International Development; it soon became a handbook for fieldworkers of nearly every organization throughout the world. The next project was a series of *Rural Technology Manuals* that dealt with specific techniques or processes, such as "How to Salt Fish" and "VITA Solar Cooker Construction Manual." The VITA *Newsletter*, published monthly with a circulation of over 17 000, provides current information to volunteers and fieldworkers. It frequently outlines new problems received at VITA headquarters and gives helpful suggestions on problems of wide general interest. In addition to the *Newsletter*, VITA officials are currently considering another, more sophisticated, periodical for general distribution.

VITA's third approach to information distribution was the Village Technology Center, where working models of tools and devices designed for underdeveloped areas are assembled and tested. These models, in some instances, are used as examples in the field, to show local villagers how to build the implements; they are frequently used in training fieldworkers, such as Peace Corps Volunteers.

New horizons, responsibilities, and friends

The next project under consideration is the VITA fieldworker. The feasibility of such a program is currently being tested; representatives at project sites and operational centers could prove an invaluable source of feedback to headquarters. A trained observer could transmit reports of needs, successes, and failures with accuracy and dispatch. Such a program might well become a necessity of the future, due to the rapid expansion of VITA's responsibilities and the resulting strain on its resources. But such a step is added expense to the organization's already meager funds. Where will the money come from?

VITA's operating budget for 1968 is $250 000. (The value of its services is estimated to be a factor of five times that amount.) Some of this money comes from philanthropic foundations, such as the Rockefeller Foundation and the Rockefeller Brothers Fund. An important part of the capital is in the form of corporate donations from such companies as Detroit-Edison, General Electric, International Business Machines Corporation, International Telephone and Telegraph Corporation, RCA, Standard Oil, Union Carbide, Xerox, and many others equally as famous. And a good part of the money will be coming from the pockets of individual contributors.

VITA, in its relations with the government, has recently dramatically gained in both stature and finances. It serves as the official technical consultant to the Peace Corps[4]; and in February 1968 received a contract for

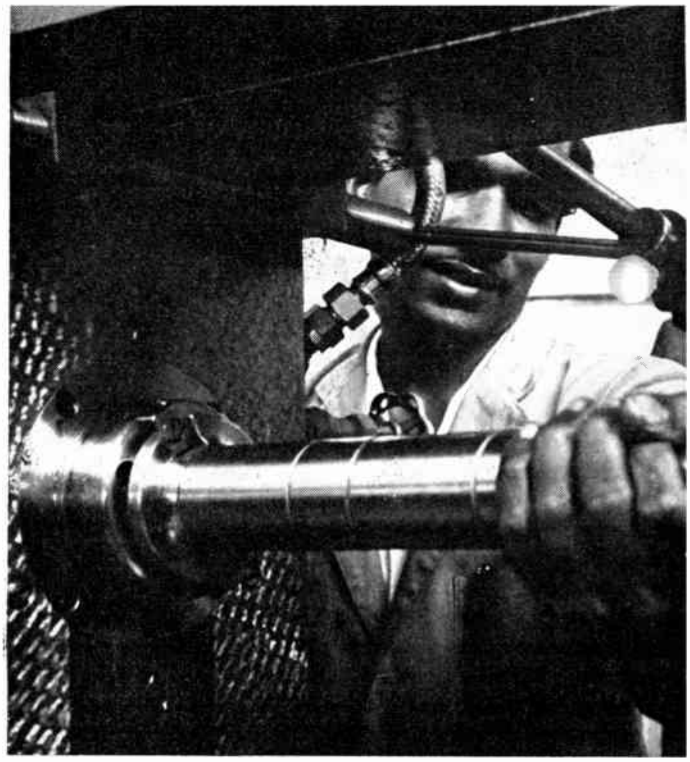
I. Inquiries classified by subject—percent*

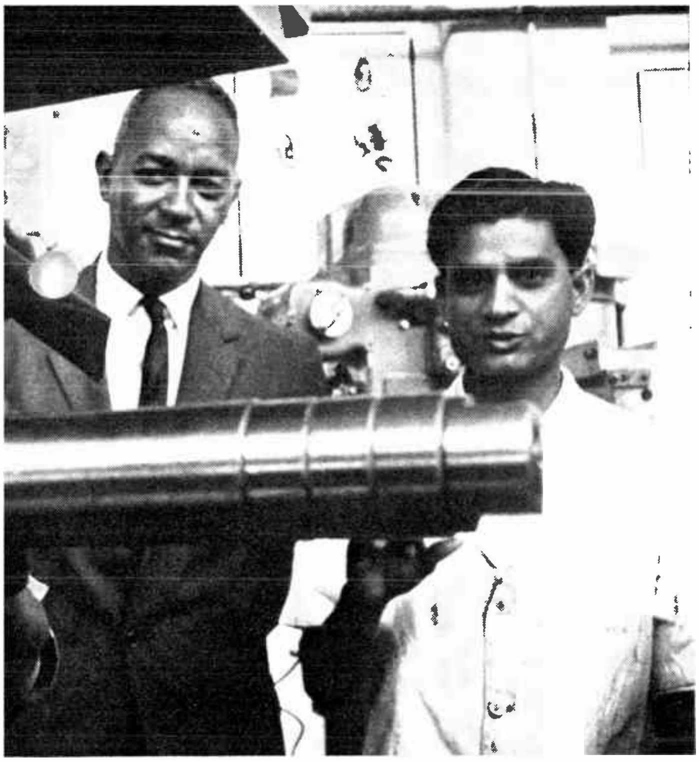
Agriculture	23	Food processing	10
Small business	14	Home improvement	7
Construction	12	Crafts	7
Education	12	Power	6
Medicine & health	12	Other	8

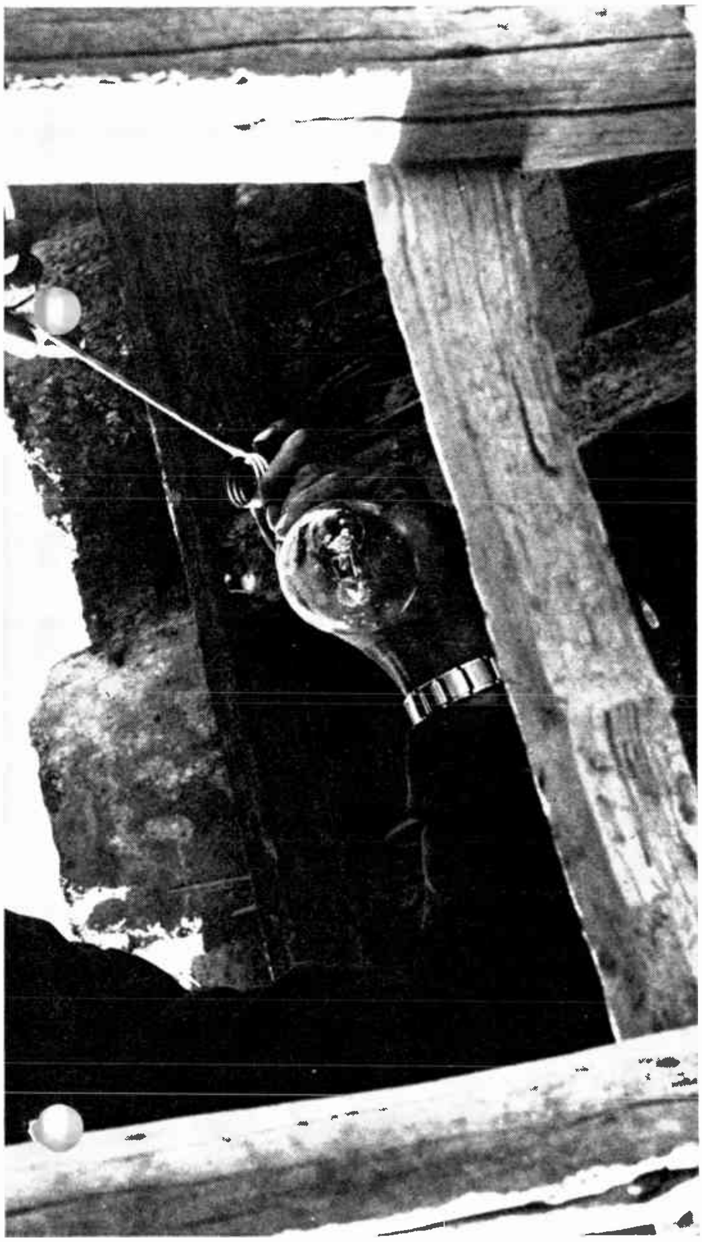
*Total is more than 100 percent because some requests apply to more than one category.

II. Inquiries by geographical area—percent

Middle East and North Africa	4
Latin America	38
Africa	19
East Asia and Pacific area	36
Europe, North America, and others	3







$20 000 to provide technical information officially to PCV's.[5] As of April 1968, VITA received a $45 000 grant from AID to act as its technical information service, replacing an ineffectual government service.

According to Richard Palmer of the Office of Private Resources, Agency for International Development, in Washington, "VITA is really first-class service, accepted by technical and business interests alike."

AID had its own Technical Information Service up until April, but it was a flop. Mr. Palmer was among those who recommended that it be abolished in favor of VITA's services. This reaction of a government agency is accolade enough to show that VITA is fulfilling an obvious need. The problems do exist, even though often on a subtechnical level; and, in order for two thirds of the world to advance, some technical answers must be supplied.

The problem: unsophistication and demodernization

The challenge of the typical problem submitted to VITA is inherent in its simplicity; its solution must depend on ingenuity and innovation, not technology alone, because, more often then not, modern technology does not *exist* in underdeveloped areas. The scientist/engineer must consider the natural environment, economy, sociologic concepts, and availability of materials; the tool, the piece of equipment, the system, or process must be utterly free of complexity and constructed of the simplest available materials.

The specific problems vary (Table I), but they can be broken down into four main categories—obtaining and using food, knowledge, shelter, and power. They can occur in almost any area of the world (Table II). Occasionally, when local conditions are so lacking of resources that a solution seems impossible, modern technology supplements the fieldworker.

The leader of an American Friends Service Committee summer project in Guatemala wanted to supply fresh water to a lonely village. The closest available water was a spring a mile away. VITA volunteer Daniel Johnson, a Schenectady engineer with General Electric, drew plans calling for the use of ¾-inch plastic pipe from spring to village, terminating in a reservoir at the receiving end. The AFSC volunteer provided the direction, the village supplied 300 man-days of labor, and CARE supplied the pipe.

Requests to VITA have traversed the entire range of human need and challenge, many strongly taxing the imagination, and even the credulity, of the recipients: the best methods for trapping and merchandising fireflies; a design for an infant's incubator heated by other than electricity; how to build a simple water pump; the design for a more efficient ox yoke. Some of the tools and techniques resulting from these inquiries could have been designed easily during the lifetime of Christ; but to the requester, they are revolutionary. Studies conducted by VITA on the feasibility of small electric power installations in backward areas revealed a sociological factor as basic as the engineering problem: The villagers, knowing nothing of electric power, had to be taught what it was, how to use it, and its advantages, before they could be at all enthusiastic about its installation.

The Rev. Jerry Smyth, a Baptist missionary in Bahia,

III. Classification of power requests by application

Type	Number	Percent of Total
Industry	279	37
Processing	206	28
Pumps and pumping	129	17
Cultivation	76	10
Well digging and drilling	32	4
Poultry	21	3
Transportation	4	1

Brazil, included the following comment in an open letter to VITA volunteers: "When a letter has been written to VITA, be sure that a crisis is involved—a crisis of concern, perhaps frustration because one sees a problem but cannot see a solution. At times one may be unable to define the problem."

Technology's lowest common denominator

CARE presented VITA with one of its most unusual problems; the solution gained worldwide headlines and recognition for all concerned. It was, superficially, a deceptively simple research project. There are many areas of the world where inhabitants have difficulty cooking food, due to lack of fuel. Would VITA study the usefulness of existing solar cookers on the market?

VITA would—and did. Existing solar cookers were very effective, but also expensive and easily damaged beyond practical repair. The evaluation team decided that a new solar cooker should be designed that would be cheap as well as easy to make, repair, and use.

Volunteer William Hillig, a GE Research and Development Center physical chemist, designed a new cooker that could be built in any village for less than $3.00, using coaxial cardboard or plywood rings, covered with aluminized plastic film, to form a Fresnel-type reflector and concentrator. The solution to the project embodied the very tenet of the VITA recipe for success: Reduce sophisticated, modern science and technology to its lowest common denominator, add generous amounts of ingenuity and innovation, stir well with human compassion, and serve to the needy of the world.

Electrical engineering aspects

The majority of VITA's queries are concerned with the growing, harvesting, and preparation of food. But the need for sources of electric power in remote areas is growing; and VITA would probably receive many more requests in this area if it had a larger pool of electrical engineering talent. As it is, requests for such information are cascading.

Even though data are requested on almost every facet and application of electrical technology (Table III), "small power sources" is the most popular topic. The power magnitudes considered fall roughly into three categories: (1) systems producing a fraction of a watt up to several watts; (2) systems from several watts to one kilowatt; and (3) systems above one kilowatt.[5]

Enough requests on this topic were received at VITA's headquarters to prompt the completion and publication of *Low-Cost Development of Small Water-Power Sites*, written by Volunteer Hans W. Hamm, a specialist on the subject and consultant to a manufacturer of water wheels and turbines. The manual gives step-by-step construction procedures, including numerous simplified designs.

IEEE students find a way

Unfortunately, water power is frequently unavailable where most needed. A missionary in a remote, technologically bankrupt area wanted a source of electricity to illuminate classrooms at night. There was no usable body of water in the area, little wind, and no commercial supply of fuel. The Schenectady IEEE Student Branch devised an answer for VITA—and won the Bendix award in the process. Strangely enough, one type of item easily available in the area was automobile and bicycle *parts*. The students solved the problem with a car alternator, driven by a yoked *water buffalo*, which charged a set of batteries during the day. In the evening, the batteries would supply enough power for lighting the school.

Contemporary problems: a challenge to the IEEE

A sample of VITA's contemporary, unsolved problems in our field shows the need of, and opportunity for, true engineering application.

Problem 12729: A Peace Corps Volunteer, working with a small, rural electric cooperative in Ecuador, needs an inexpensive method of demonstrably testing electric consumption meters to gain public confidence in their accuracy. The meters in question are simple 120-volt, single-phase devices rated at 5 or 15 amperes, such as Sangamo type 05, Westinghouse type CS, and General Electric type 1-30-5. The only test equipment presently available to the volunteer is a Simpson 260 VOM.

Problem 12706: A volunteer with the Unevangelical Fields Missions, stationed among the Waiwai Indians in Guyana, wants enough power to supply a village of 600 with lights for about three hours each night. Power requirements would include approximately 250 lights plus some small machinery, with a maximum transmission length of about one kilometer. ("Future expansions must be considered, as the population is expanding rapidly!") The missionaries had considered using three Petter diesel plants, with a total rating of 12 kW. However, step-up transformers are prohibitively expensive, as is diesel fuel; and none of the missionaries are mechanically or technically able to perform even basic maintenance. Wood is plentiful; would a steam turbine be practical? Could a steam unit of this capacity be transported in a Cessna? Is steam generation safe and foolproof, or does it have to be carefully watched while in operation? Is there any maintenance necessary, and can it be performed by nontechnical personnel?

(*Anyone interested in answering either problem should address replies to:* VITA, College Campus, Schenectady, N.Y., 12308.)

VITA and the IEEE—why volunteer?

Its obvious that fieldworkers in underdeveloped areas need advice on electrical engineering—some of them have, in truth, little or no conception of the problem, let alone the solution. On the other hand, a true engineer loves a challenge, especially something offbeat, out of the ordinary, such as is represented by VITA and the requests for help it receives.

Volunteering for VITA service is simple. An individual writes for a résumé form, fills it out (about five minutes' work), and returns it to the Schenectady headquarters. The résumé is informal, with no requirements attached except a willingness to help others. When a problem is received, the volunteer is asked if he will accept it; if he does, he is given a period of time in which to develop a solution. Interested volunteers usually, on their own initiative, correspond with the requestor in the field.

"What's in it for me?" Nothing, perhaps, except the satisfaction of answering a direct challenge with a valid, foolproof solution, seeing it applied and working, and receiving the thanks and warm appreciation of a grateful people.

Of the several IEEE members associated with VITA, probably the most personally involved is Dr. Don Lebell (SM) of the San Fernando Valley Section of the IEEE. Dr. Lebell, head of Lebell Consulting Company, Encino, Calif., has been stationed in Santiago, Chile, for almost two years under a contract with the Agency for International Development in the capacity of a consulting engineer for industrial development. He is also a VITA volunteer, as well as a user of VITA's information services. Officially, he is in the area to stimulate and develop small-scale industry; but his personal interest and concern with this assignment goes beyond the industrial realm.

Lebell, an enthusiastic radio amateur, set up a ham radio station in Santiago, using his own equipment at his own expense. His rig attracted much local interest; and soon he was training interested people in the Santiago area.

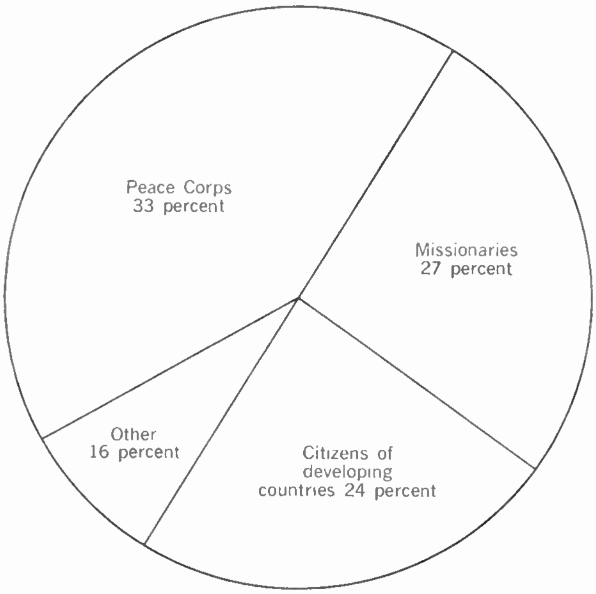
Local interest has been so pronounced that Dr. Lebell decided to install a permanent amateur station at Santiago before the termination of his assignment on September 1, 1968. His plan has been to request donations of extra or idle equipment from hams in the states, and convert this to a permanent installation. In his own words: "Any ham installation that I have ever visited has had plenty of miscellaneous equipment lying around on the shelves, gathering dust. We're interested in any 10- to 20-meter single-sideband amateur equipment that we can lay our hands on; and this project could provide an opportunity for many United States radio amateurs to help their less fortunate counterparts in Chile. It could provide an added bond of friendship between the two countries."

Unfortunately, as of June 18, Dr. Lebell's requests for help have fallen on disinterested ears. A notice in *The Grid Bulletin*, an IEEE publication in the Los Angeles area, has netted not a single tube or transistor, let alone enough equipment to put an amateur radio station on the air. He had hoped for a heavy response from individual IEEE members and hams in the California area, and perhaps a few replies from industry. So far, he has been sadly disappointed.

If Don Lebell's radio station were part of his official government assignment he would have little difficulty obtaining the necessary equipment. But since this is an undertaking of his own personal concern and commitment he must rely on the good will of interested individuals and private industry, which, so far, has failed to materialize. (*Editor's note: Interested parties may contact Don Lebell at U.S. AID, P.O. Box 13120, Santiago, Chile; or, after September 1, at Lebell Consulting Company, 16200 Ventura Boulevard, Encino, Calif.*)

Several other members of the IEEE have capitulated to the lure of the challenge, including, among VITA's Board of Directors, such names as Henri Busignies of ITT, Walker Cisler of Detroit Edison, and H. Myrl Stearns of Varian Associates. They are lending their engineering talents to help other people help themselves.

Source of inquiries



The author wishes to thank the International Labor Office and Volunteers for International Technical Assistance for supplying the photographs presented in this article.

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The early history of electronics

I. Electromagnetics before Hertz

The first of a series of articles by an authority on the history of electronics traces the descent of that branch of technology from one of its parent sciences, electromagnetics. The work of Hertz and the beginnings and development of radiotelegraphy after the flowering of the other parent science, electron theory, will be the subjects of future articles in the series.

Charles Süsskind *University of California*

Electronics as a branch of technology had its beginnings in two important developments of 19th century physics: the generation and detection of electromagnetic waves, and the discovery of the electron. Practical invention outstripped theoretical development again and again. Devices employing cathode rays were utilized before it was proved that the rays were charged particles. Electromagnetic waves were produced and observed before anyone attempted a definitive experiment. Crystal rectifiers were mass-produced long before the nature of semiconductors began to be understood. Such occurrences are not uncommon in the history of technology. A practical discovery or invention often leads to experimental research and then to basic revelations of quite general import. What is much more rarely achieved is a purely theoretical prediction of a phenomenon that proves to be of great technological significance. The electromagnetic theory of James Clerk Maxwell (1831–1879) was such an achievement. It was destined to become a cornerstone in the foundations of electronics.

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Electromagnetic theory

To appreciate just how great Maxwell's contribution was, we must recall that throughout the first half of the 19th century, electrical theory was dominated by the concept of *action at a distance*, in analogy with gravitational theory. The electrical discoveries of Charles Augustin Coulomb (1736–1806), Hans Christian Oersted (1777–1851), and André Marie Ampère (1775–1836) were easily accommodated within this concept; only the flow of electricity along conductors required certain modifications. But with the discovery of electromagnetic induction by Joseph Henry (1797–1878) and Michael Faraday (1791–1867), it became necessary to postulate an electromagnetic *medium* (similar to the "ether" proposed by other physicists to account for optical phenomena) in which invisible forces were at work. Faraday intuitively thought of electricity and magnetism in terms of fields of force. He saw the pattern produced by iron filings near the poles of a magnet merely as an indication of the physical state of the surrounding space, and an electrified body was to him similarly a center of lines of force. These novel and brilliant ideas were not elaborated mathematically, except in a very sketchy way. A more exact formulation was first provided by Carl Friedrich Gauss (1777–1855) in his famous theorem relating the flux of force lines out of a region to the total charge within that region. But not until Maxwell did the electric and magnetic *fields* come to be considered as the fundamental quantities, to be related by differential equations.

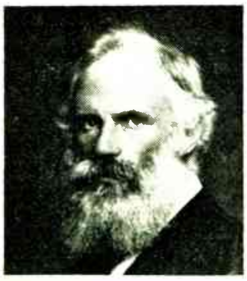
Maxwell believed that it should be possible to reconcile the roles of the ether and of the postulated electromagnetic medium. He conceived of charge as a displacement in the medium; and he thought of a change in the displacement as an electric current, to be added to any actual conduction current that may be present. With these new concepts Maxwell formulated his famous equations, in which he also accounted for Faraday's law of induction and introduced the notion of a magnetic vector potential. Although an impressive background of mathematical theory relating to fields and potentials was already available in the work on gravitational systems by such distinguished mathematicians as Pierre-Simon Laplace (1749–1827) and Simeon Denis Poisson (1781–1840). Maxwell considerably extended the existing theory and provided a fitting theoretical framework for the intuitive concepts of Faraday. But the greatest result of all was his prediction that any perturbation in the electromagnetic field would not be instantaneously perceived at another point in space. Rather, the change would propagate as a wave, with a finite velocity, which he was able to show would be equal to the velocity of light.

This result, which Maxwell announced in 1864, may be thus considered as perhaps the greatest achievement of 19th century physics. In a single clean sweep, he replaced the no longer tenable action-at-a-distance theory by a field theory and he showed that optics was a branch of electromagnetism.

Even after he elaborated it in a two-volume treatise,[1] Maxwell's theory was not universally accepted by his contemporaries, especially since measurements based on one of its deductions (that the dielectric constant would equal the square of the refractive index) did not always bear it out. Additional support for Maxwell's theory was provided by the researches of John Kerr (1824–1907), who showed in 1875 that certain dielectrics exhibited double refraction under the action of an electrostatic field,[2] as well as by a number of other investigations relating mainly to the fields produced by moving charges. Nevertheless, a small gap remained between optics, in which energy travels through space without being attached to anything, and classical electrodynamics, where the energy interchange takes place between material bodies comprising a single system. Several theoreticians addressed themselves to the problem of closing the gap, notably FitzGerald, who published a series of three papers on the possibility of originating wave disturbances in the ether by means of electric forces.[3] In the last of these papers, published in 1882, he declared that it seemed "highly probable that the energy of varying currents is in part radiated into space"; and in the following year he calculated the quantity of energy transferred to the ether by a variable current.[4] This was the "magnetic oscillator," in which the current in a small loop was varied sinusoidally. The crucial problem was to make the frequency of oscillations sufficiently high, since the calculation showed the energy to be proportional to the fourth power of the frequency. At the British Association meeting later in the same year, FitzGerald proposed a method for producing electromagnetic disturbances of sufficiently short wavelengths, by discharging a capacitor through a small resistance, that would make it possible to produce waves as short as 10 meters in wavelength, or even shorter.[5]

The method proposed by FitzGerald had had its beginnings more than half a century earlier. In 1824, the astronomer Felix Savary (1797–1841) had found that steel needles became magnetized in alternating layers in the vicinity of a spark discharge resulting from short-circuiting a Leyden jar, and had speculated on the oscillatory nature of the discharge.[6] During a similar experiment, Henry, in 1842, noticed that the current flowed first one way and then the other—and, incidentally, that magnetization could be obtained over astonishing distances.[7] A similar effect was also noted by Peter Theophil Riess (1804–1883).[8] A qualitative argument by which the oscillatory behavior of the magnetization could be explained was first provided by the great physiologist and physicist Hermann von Helmholtz (1812–1894). In his classic treatise on the conservation of energy,[9] which laid the foundations for the mathematical treatment of the kinetic theory of heat, Helmholtz argued that this observation fitted in with another made even earlier by William Hyde Wollaston (1766–1828). In his attempts to decompose water electrolytically by spark discharges, Wollaston had found that the two component gases were evolved on both electrodes, and that the amounts evolved increased as electrode areas were decreased. All these observations fell into place, said Helmholtz, when it was assumed that the discharge was not a simple flow of electricity but rather a backward and forward flow in oscillations that became gradually smaller; not only that—the nature of the energy storage demanded such an oscillatory discharge on theoretical grounds.

This point was taken up in 1853 by William Thomson (later Lord Kelvin), who developed the first solid mathematical analysis of transient electric currents.[10] By taking into account not only the capacitance C and resistance R, but also the inductance L (which he introduced, without explanation, as "electrodynamic capacity"), he derived the formula for the frequency of damped oscillations in an RLC circuit: $f = (1/2\pi)[(1/LC) - (R^2/4L^2)]^{1/2}$. The analysis was verified by Berend Wilhelm Feddersen (1832–1918) in a series of ingenious experi-



George Francis FitzGerald (1851–1901) was born in Dublin, where he lived all his life. He was a nephew of G. Johnstone Stoney (1826–1911), the Irish physicist who named the "electron," and was educated privately by a woman tutor who was the sister of the great mathematician and logician, George Boole (1815–1864). FitzGerald attended Trinity College and became professor of natural and experimental philosophy there at 30. He struggled continually to make Dublin a center of learning in the physical sciences and in engineering and sought to improve educational standards generally. He made telling contributions to the understanding of electromagnetic waves and of electrolysis, and was from the first among the minority who supported the view that cathode rays were streams of charged particles. In 1892–1893, he served as president of the Physical Society. He died in Dublin on February 22, 1901. (See "Introductory and biographical," in *The Scientific Writings of the Late George Francis FitzGerald*, J. Larmor, ed. Dublin: Dublin University Press, 1902.)

ments beginning in 1857, in which he made use of a rotating mirror to obtain photographic proof that the discharge was oscillatory.[11] Feddersen sent his results to W. Thomson, who was most gratified to receive such a confirmation,[12] the more so since he had been in the meantime occupied with the theory of electric signaling along wires and cables.[13] (That an insulated submarine or subterranean cable forms a large capacitance with the surrounding medium that must be taken into account in the operation of the cable had been pointed out by Faraday a year before in two articles.[14])

It was against this background that FitzGerald, 30 years later, made his suggestion that radiation should be generated by the utilization of the oscillatory discharge of a capacitor to produce a rapidly varying current in a circular loop of wire. The fields associated with the capacitor itself would play no direct part in generating the radiations; it would be the magnetic field of the loop that would act as the source. He made no proposal as to how such waves could be detected, nor did he (or anyone else) actually attempt the experiment.

The arrangement by which incontrovertible experimental proof of Maxwell's theory was ultimately obtained in 1887 was actually quite similar. Use of the capacitor simply for energy storage gave way to a scheme in which the discharge spark itself became the source of radiations that could be detected by a second, similar arrangement at some distance from the first. But all that came some five years later and afterwards proved to have been anticipated by a number of experimenters who lacked the theoretical background or the experience to identify their observations with Maxwell's predictions.[15]

Practical anticipations: Galvani and Henry

Attempts at electrical "wireless" communications have a long history, although one must distinguish between genuine radio (wave) propagation and systems in which the intended mode of transmission was by induction or conduction. Communication with moving trains by means of signals sent on a wire laid along the tracks is an example of induction signaling. Communication by conduction without the use of connecting wires also had its day. The conducting medium was variously wet earth, fresh water, or (most successfully) salt water. This method was at one time considered to be of sufficient practical interest (for communications with beleaguered garrisons, across rivers, with ships, and with lighthouses and other isolated spots to which connecting wires could not be conveniently carried) to cause at least one government to instigate an exhaustive series of tests regarding the feasibility of the various methods proposed. (A paper on "Signalling Through Space" was read before the British Association's 1894 meeting in Oxford.[16])

We may safely disregard all of these alternate proposals in the present context. Accounts written around the turn of the century, before the advantages of radio communications had shown up the manifest limitations of competing systems, are by no means so selective. J. J. Fahie's classic *History of Wireless Telegraphy* devotes as much space to such systems as to radio[17]; and even a history published a quarter of a century later[18] suffers from a similar disproportion. We shall not try to rehearse the accomplishments of the various scientists, engineers, and inventors whose attempts proved to be merely so many false starts toward the solution of the problem of radio communications. But there are several genuine precursors of radio communications whose results deserve mention, even though they had no discernible effect on the development of the subject.

Observations of electromagnetic-wave propagation from man-made electrical disturbances have been made probably for as long as there have been ways to produce moderately large sparks. In the course of his celebrated experiments begun in 1780, Luigi (Aloisius) Galvani (1737–1798) observed that sparking from an electrostatic generator could cause convulsions in a dead frog at some distance from the machine. Galvani also noted that a luminous discharge emanated from the center conductor of a freshly charged Leyden jar and presently disappeared, but was renewed whenever a spark was elicited nearby: ". . . we have accidentally observed a luminous pencil to shine continuously in the dark from the pointed conductor of a charged Leyden jar and after some time to disappear of its own accord. But after it disappeared, if the jar was put at a certain distance from the conductor of the machine and a spark was elicited from that conductor, the same pencil again appeared at the very moment the spark was drawn, but soon vanished, and so alternately arose when the spark was drawn and was extinguished."[19]

We have also seen that Henry had noticed in 1842 how magnetization could be induced at considerable distances. "A single spark from the prime conductor of the machine," he wrote, "of about an inch long, thrown on the end of a circuit of wire in an upper room, produced an induction sufficiently powerful to magnetize needles in a parallel circuit of wire placed in the cellar beneath, at a perpendicular distance of thirty feet with two floors and ceilings, each fourteen inches thick, intervening. The author is disposed to adopt the hypothesis of an electrical *plenum*, and from the foregoing experiment it would appear that the transfer of a single spark is sufficient to disturb perceptibly the electricity of space throughout at least a cube of 400,000 feet of capacity; and when it is considered that the magnetism of the needle is the result of the difference of two actions, it may be further inferred that the diffusion of motion in this case is almost comparable with that of a spark from a flint and steel in the case of light."[20]

That was a remarkable inference, in which Henry nearly divined the electromagnetic nature of light. At any rate, his intuition regarding the relationship came closer to the truth than that of the many other experimenters who observed similar effects, both before and after Maxwell, as the increasing use of electric apparatus began to afford many more opportunities for such observations.

John Joseph Fahie (pronounced "Fay," 1846–1934) was born in Tipperary, Ireland, and spent most of his working life as a telegraph engineer in Persia. He turned his ample spare time to good account by authoring a number of papers on telegraphy, and soon became interested in the historical background of his profession. In 1884 he published *A History of Electric Telegraphy to the Year 1837* (E. and F. N. Spoon, London and New York) and followed it with *A History of Wireless Telegraphy* in 1899. This book enjoyed some popularity beyond engineering circles owing to the public interest (and drop in telegraph shares) that the first demonstrations of radiotelegraphy had aroused, and was reprinted, published in a subsequent edition in 1901, and reissued in the United States by Dodd, Mead and Company in 1902. During the remainder of Fahie's life his principal interest was in Galileo, about whom he published two books and several articles; but he also remained interested in electricity until his death in Broughton-in-Furness, Lancashire, on June 12, 1934. (See Whitehead, E. S., *The Life and Work of John Joseph Fahie*. Liverpool: University Press of Liverpool, 1939.)

Edison and E. Thomson

A particularly striking observation was made by Edison in 1875. He reported that sparks produced when an electric circuit was interrupted with an ordinary telegraphic key could be picked up between the free end of a wire attached to a metal plate placed in the vicinity and any other metallic object.[21] He was astute enough to note that the sparks produced electricity of a novel sort, one that appeared to have no polarity and did not affect a gold-leaf electroscope in the slightest. (Both properties follow from the fact that this was rapidly alternating current, not direct current.) Edison concluded that the phenomenon was not electrical in nature and thought he had discovered a new force, which he named "etheric force." The phenomena observed attested new "principles, until now buried in the depths of human ignorance," he was quoted by the newspapers as saying.[21] The next report stated that if a box containing "two carbon points be brought within a short distance of any of the working telegraph sounders, used at the Western Union Telegraph Office, Dey Street and Broadway, the sparks, heretofore described by Mr. Edison, he states, at once make their appearance between the points. The flashes thus produced correspond with the opening and closing of the circuit of the magnet, and thus the signal or message that is passing through the instrument is reproduced in the form of light, within the Edison box. No connection of the carbon points by wires with the telegraph instrument is necessary. Simply bringing the box near to the instrument is sufficient."[22]

Here was "wireless" telegraphy indeed! But for once Edison's instinct played him false. He abandoned his usual preoccupation with commercial applications—he was bent on proving that he was dealing "with a new force, as distinct from electricity as light or heat is."[23]

This contention came to the attention of Elihu Thomson, then a young science teacher in Philadelphia. He remembered an observation that he had made four years earlier, in 1871. He had used a Rühmkorff coil (an induction coil or transformer with a spark gap across the secondary winding) much favored in classroom demonstrations because it produced a continuing train of sparks when a battery was connected across the primary winding. When an array of Leyden jars was connected across the spark gap, the size and color of the sparks changed, as they did with another capacitor arrangement—connecting one side of the gap to a water pipe and the other to a metal table top. With this circuit, he had been startled to find, the sparks were suddenly all around him: he could draw them with a knife from the table top, from water pipes across the room, from the frame of a steam engine 30 feet (9 meters) away; he even managed to light a gas burner by touching it with the knife.

He told his colleague, Houston, about his findings. Houston agreed that they were worth publishing, and evidently believing that his own name would be more effective in securing publication, sent an article to the Franklin Institute in which the 18-year-old Elihu Thomson was nowhere mentioned.[24] The sparking phenomenon was described only in passing, as a fact "showing great loss of electricity"; the body of the article was devoted to the method of increasing the current in the primary spark by connecting the induction coil to a large capacitor.

Determined to show that Edison's sparks were really electric, E. Thomson now decided to elaborate his previous experiment. He went back to his Rühmkorff coil, this time grounding one side of the spark gap and connecting the other to a large tin still, which he insulated by mounting it on a glass jar. To detect the sparks, he used (like Edison) a wooden box open at one end and containing two graphite pencil points almost touching, but with one of them connected to a large brass knob on the outside of the box. After adjusting the gap to yield maximum spark, he found that he could detect sparks anywhere in the room with his "receiver" and even between a pencil held in the hand and any insulated metallic object. He obtained the same result in an adjoining room, then on the next floor, and the next, until he had climbed to the very top of the building, the sixth-floor observatory. There he demonstrated the effect to the professor of astronomy, Monroe Benjamin Snyder (1848–1932). The astronomer watched with fascination as Thomson drew sparks from the door knob, from the eyepiece of the telescope, and from a group of small metallic objects in a glass case. Many years later, Snyder recollected how they next moved on to the large door knob of the observatory library, some 100 feet (30 meters) from the experimental apparatus. Here they again drew large sparks.[25]

But to Elihu Thomson, all these observations were incidental to refuting Edison's claim, which he did by a series of experiments with the equipment. Once again Houston wrote the report, this time including a mention that the experiments were carried out "in connection with my friend, Professor Elihu Thomson, of Philadelphia."[26] A more complete account under joint authorship appeared a few months later.[27]

The controversy continued for a while. A spirited correspondence ensued in the pages of the *Scientific American*.[28] But the main participants soon found more important matters occupying their attentions. E. Thomson turned to the design of more efficient dynamos; Edison went on to develop the carbon microphone and to invent the phonograph. Both men were involved in the preparations for the Philadelphia Centennial exhibition, which was held in 1876 to celebrate the first 100 years of the United States of America. David Woodbury, Thomson's biographer, says: "Elihu Thomson never regretted his failure to be the father of wireless. In later years he said frankly that in those experiments of 1875 he had fully realized that he had discovered the germ of a new system of communication, but had not been wise enough to exploit it."[29]

Edison was more rueful: "What has always puzzled me since," he is quoted as saying many years later, "is that I did not think of using the results. . . If I had made use of my own work I should have had long-distance wireless telegraphy."[30]

S. P. Thompson

Perhaps the final chapter in this episode came when E. Thomson's near namesake and contemporary, 24-year-old S. P. Thompson in faraway London, eager to win his scientific spurs, performed a series of well-designed experiments that likewise went to show that the effects Edison had observed were electrical in origin. S. P. Thompson's attention was drawn to the controversy by his teacher, Frederick Guthrie (1833–1886), professor of physics at the Normal School of Science in London (South Kensington). Guthrie had read the report of Dr. Beard of New York, and had perhaps reviewed the manuscript of an article by Beard that eventually appeared in a London quarterly edited by friends who were Guthrie's colleagues.[31] George Miller Beard (1839–1883) was a well-known physician and pioneer American neurologist who had long been interested in electricity. His book, *The Medical and Surgical Uses of Electricity*, first published in 1871, was a great success on both sides of the Atlantic and went into at least eight editions over the following 20 years. Beard's interest in Edison's observations arose from the circumstance that the sparks appeared to elicit no physiological response. Whatever the manner in which word of Beard's work first reached Guthrie, he now set young S. P. Thompson to performing an experiment in which an especially effective source was used and the resulting sparks were detected by means of the luminous discharge in a glass tube containing a rarefied gas. A rotating-mirror arrangement near the tube showed that the discharge was oscillatory, a finding that was confirmed by the erratic behavior of a galvanometer and of an electroscope. But even after going to the trouble of setting up this more sophisticated experiment, Thompson concluded that the phenomena could be all attributed to induction.

The paper reporting S. P. Thompson's observations "On Etheric Force" was read before the Physical Society in London on January 29, 1876, and in due course appeared in published form.[32] It was an auspicious start of a brilliant career. It is significant that S. P. Thompson became aware of E. Thomson's 1871 experiments while his own paper was in proof, and he mentioned them in a footnote. He ascribed them to Houston, as well he might, since E. Thomson was not mentioned in the account[33]; and later writers have also tended to give the full credit to Houston. By contrast, the name of the man who had instigated S. P. Thompson's research, Frederick Guthrie, does not even appear in the later paper. One might anticipate that the relationship between the 18-year-old E. Thomson and Houston, who was six years his senior, would henceforth be fraught with difficulties, but that S. P. Thompson would retain the highest regard for his mentor; and so it proved. Thomson and Houston eventually had a falling out; whereas in 1901, upon being elected president of the Physical Society, S. P. Thompson spoke of Guthrie (who had been the society's founder) as a man "whose memory many of us cherish with a personal regard and affection that goes far beyond the high esteem in which his name is deservedly held for the good work which he did as an experimental investigator of great originality."[34]

Dolbear

Another precursor of radiotelegraphy, and indeed of radiotelephony, was the American physics teacher Dolbear. In 1882, he applied for the first of his patents (finally granted on October 5, 1886), on a telephone system whose transmitter comprised an induction coil (transformer); the secondary winding of the transformer was connected between ground and a capacitor whose other terminal remained floating in free space, and the

Elihu Thomson (1853–1936) (left), born in Manchester, was taken to Philadelphia at the age of five, attended the Central High School (then a degree-granting academy on the European *gymnasium* plan), and became a chemistry assistant there at 17. Together with the professor of natural philosophy, Edwin James Houston (pronounced "Hows-ton," 1847–1914), he engaged in a series of chemical and electrical experiments that led to improvements in the design of dynamos and other electric devices and eventually resulted in the formation of the Thomson-Houston Company, with factories in Lynn, Mass., in 1882. (This company was merged with the Edison General Electric Company and several smaller establishments in 1892 to form the General Electric Company, with headquarters in Schenectady, N. Y.; the name of the original concern still survives in the French firm Compagnie Française Thomson-Houston, or C.F.T.H.) Thomson went on to become one of the most distinguished electrical engineers of his time. He developed resistance welding, the integrating watthour meter, and dozens of other devices. He was one of the first members of the AIEE upon its foundation in 1884 (and served as its President in 1889); was acting president of M.I.T., 1920–1922; and was recipient of the Royal Society's Hughes Medal in 1916, of the Franklin Institute's Franklin Medal in 1924, and of the IEE's Faraday Medal in 1927. (See Woodbury, D. O., *Beloved Scientist*. Cambridge, Mass.: Harvard University Press, 2nd printing, 1960.)

It may be useful here to distinguish among his various namesakes who achieved scientific fame. (1) (Sir) Benjamin Thompson (right), later Count von Rumford, was the Massachusetts-born, Harvard-educated British and Bavarian soldier and civil servant who contributed to the development of thermodynamics and made several practical inventions relating to clothing, cooking, and fuel economy. In 1799 he founded the Royal Institution of Great Britain, whose coveted Rumford Medal is named after him, as is the same award of the American Academy of Arts and Sciences. (2) (Sir) William Thomson (1824–1907), later Lord Kelvin, was born in Belfast and educated at Cambridge and at Glasgow, where he served as professor of natural philosophy from 1846 to 1899, making important contributions to many branches of physics. He played an active part in the design and laying of the first transatlantic cables and in the establishment of rational electrical units. The Thomson effect in thermoelectricity and the absolute centigrade unit of temperature (degree Kelvin) are named in his honor. (See Thompson, S. P., *The Life of William Thomson*. London: Macmillan, 1910.) (3) Silvanus Phillips Thompson (1851–1916) was a prominent engineering educator, a graduate of the University of London, and Principal of the City and Guilds of London Finsbury Technical College from 1885 to his death. (This college, discontinued in 1926, was a combined trade school and secondary school; it was distinct from the City and Guilds' college-level institution, the Central Technical College at South Kensington in London, which became one of the three constituent colleges from which the University of London's Imperial College of Science and Technology was formed in 1907.) He was successively president of the IEE (1899), of the Physical Society (1901–1902), and of the Optical Society (1905). In addition to several standard textbooks on electrical engineering, he published biographies of the telephone pioneer Phillipp Reiss (1834–1874), Michael Faraday, and Lord Kelvin, and translated the *De Magnete* of William Gilbert (1540–1603) into English. (4) (Sir) Joseph John Thomson (1856–1940) was the discoverer of the electron.

primary winding was connected to a battery through a microphone.[35] The telephone receiver, some distance away, was connected between ground and a battery, with a capacitor interpolated between receiver and battery; the other terminal of the battery was connected to still another capacitor whose other terminal again floated in free space.

Dolbear thought that communication took place through the ground. His description made much of the fact that opposite terminals of the two batteries at transmitter and receiver were effectively grounded. "Suppose that at one place there be apparatus for discharging the positive pole of the induction coil into the ground, say 100 times per second," he wrote, "then the ground will be raised to a certain potential 100 times per second. At another point let a similar apparatus discharge the *negative* pole 100 times per second; then between these two places there will be a greater difference of

Thomas Alva Edison (1847–1931), perhaps America's most prolific inventor, had little formal schooling. He became an itinerant telegrapher at 16 and invented several labor-saving telegraphic devices. He turned to virtually full-time inventing at 22, when he also became a partner in the first firm of consulting electrical engineers; and in 1876, he founded the first industrial research laboratory, at Menlo Park, N.J., which became the prototype of all such institutions. Among his most important inventions are quadruplex telegraphy, the phonograph, the first incandescent lamp, and the mimeograph method of stencil printing. His discoveries of electron emission and of the effect of a spark discharge brought him close to scientific fame as well, but he did not follow up on them. (See Josephson, M., *Edison*. New York: McGraw-Hill, 1959.)

potential than in the other directions, and a series of earth currents, 100 per second, will flow from the one to the other."[36]

He also noticed that he obtained better results when the two capacitors whose one plate was in air were elevated. For instance, he employed a gilt kite carrying a fine wire from the secondary coil of the transmitter, and an insulated tin roof as a terminal for the receiver capacitor. The best results were obtained when the transmitter was well grounded. Not only that—the telephone could pick up signals even when it was detached from the circuit altogether, provided the receiver (the electrostatic microphone of his own design) was grounded at one terminal and held in the hand of a person who was himself well insulated from the ground. "A person standing on the ground at a distance from the discharging point could hear nothing," he reported, "but very little standing upon ordinary stone, as granite blocks or steps; but standing on asphalt concrete, the sounds were loud enough to hear with the telephone at some distance from the ear. By grounding the one terminal of the induction coil to the gas or water pipes, leaving the other end free, telegraph signals can be heard in any part of a big building and its neighborhood without *any connection whatever*, provided the person be well insulated."[36]

This was not the first description of this particular phenomenon. On March 23, 1882, Dolbear had read a paper in London "On the Development of a New Telephonic System."[37] Many distinguished engineers were in the audience. (The Society of Telegraph Engineers and of Electricians was the predecessor of the Institution of Electrical Engineers.) Dolbear demonstrated his condenser microphone by setting up a dozen receivers in the lecture hall and putting the transmitter in an adjoining room, where another person counted to ten, whistled "God Save the Queen" and "Yankee Doodle," and performed on a cornet. As a climax of the demonstration, he said that he had found it unnecessary to have his device attached to the circuit at all; he disconnected it from the telephone wire and held it to the ear of the chairman, who reported solemnly: "I hear the sound perfectly. It was about as loud in my ear as the cry of a new-born kitten."

Dolbear demonstrated his apparatus again in 1884 at the Electrical Exhibition in Philadelphia, convinced all the while that conduction through the earth was the mechanism of transmission. Others sought to explain the results on the basis of induction. After seeing some of Dolbear's experiments and repeating them, Houston pontificated that "the experiment is simply an exceptional application of the principles of electrostatic induction, and I am not at all sure but what it may be susceptible of a great increase in delicacy, and thus become of considerable commercial value."[38]

But Dolbear also claimed to have established communication over fairly long distances, up to 13 miles (20 km). It is much more likely that his experiments were actually manifestations of electromagnetic-wave propagation through air. Moreover, they foreshadowed the development of radiotelephony, which was to be many years in the making even after radiotelegraphy had been demonstrated in the mid-90's. It is doubtful whether Dolbear could have recognized in his results confirmation of Maxwell's prediction or, for that matter, whether he had ever heard of Maxwell's equations. If he had, he might have provided the necessary proof *and*

David Edward Hughes (1830–1900) was born in London and then taken to the United States at the age of seven. In 1855, he patented a type-printing telegraph that was quickly adopted in the U.S. and in several European countries. He became even better known upon the invention of a *microphone* (a term he originated) that depended on the variation of the resistance of two conductors in loose contact. His microphone, patented after he settled in London in 1877, brought him a large fortune; when he died on January 22, 1900, childless, he left nearly half a million pounds to scientific institutions and London hospitals. He also invented an "induction balance," a sensitive meter that incorporated his microphone.

Amos Emerson Dolbear (1837–1910) was born in Norwich, Conn. He was graduated from Ohio Wesleyan University in 1866 and became professor of physics at Tufts College in Boston in 1874. In 1880 he made his principal invention, the condenser microphone receiver, which earned him a Silver Medal in Paris in 1881 and a Gold Medal in London in 1882; but he also made other investigations in electroacoustics and designed many instruments for use in this and allied fields. His receiver innovation involved him in litigation with the American Bell Telephone Company, which successfully sued him for infringement of Bell's original 1876 patent. (126 U.S., decided on March 19, 1888; see Rhodes, F. L., *The Beginnings of Telephony*. New York and London: Harper, 1929.)

gone on to base his discovery on a much firmer foundation.

Hughes

Still another inventor came even closer to the invention of radiotelegraphy, in that he believed that he had discovered a new principle but was discouraged from further experimentation by the negative opinion of a distinguished colleague. As a result, the inventor, D. E. Hughes, did not publish his observations until well after others had re-established these principles.

The full story did not come out until 1899, when Fahie was preparing the first edition of his history of wireless telegraphy.[39] He wrote to Hughes saying that he had heard of some earlier experiments and asking for detailed information. With a restraint that may well be unique in the annals of invention, Hughes at first refused: "At this late date I do not wish to set up any claim to priority, as I have never published a word on the subject; and it would be unfair to later workers in the same field to spring an unforeseen claimant to the experiments which they have certainly made without any knowledge of my work." He then reconsidered his decision and sent Fahie a full account. At the same time, he sent copies of the correspondence to the *Electrician* in London, where it was published a week later,[40] though it ultimately also became an appendix in Fahie's book.

It appears that in 1879, Hughes noticed that his microphone reacted whenever the current flowing in a nearby coil was interrupted, regardless of whether the microphone circuit was connected to the coil or not. He determined that the loose contact or "microphonic joint" inherent in his device was acting as a receiver of some invisible emanations from the sparks accompanying the interruptions and confirmed that a similar effect was obtained from sparks produced electrostatically. When he had satisfied himself that the results were reproducible, he invited several scientists, Fellows of the Royal Society among them, to witness the phenomenon. "They all saw experiments upon aërial transmission," he wrote to Fahie, "by means of the extra current produced from a small coil, and received upon a semi-metallic microphone, the results being heard upon a telephone in connection with the receiving microphone. The transmitter and receiver were in different rooms, about 60ft. apart. After trying successfully all distances allowed in my residence in Portland-street, my usual method was to put the transmitter in operation and walk up and down Great Portland-street with the receiver in my hand, with the telephone to the ear.

"The sounds seemed to slightly increase for a distance of 60 yards, then gradually diminish, until at 500 yards I could no longer with certainty hear the transmitted signals. What struck me as remarkable was that, opposite certain houses, I could hear better, whilst at others the signals could hardly be perceived."

He had discovered the phenomenon of standing waves produced by interference between incident and reflected waves, but he did not realize that until many years later. Still he went on experimenting, and on February 20, 1880, three really important scientists called on him: William Spottiswoode (1825–1883), the president of the Royal Society, accompanied by the two secretaries, Thomas Henry Huxley (1825–1895) and Sir George Gabriel Stokes (1819–1903), who had been Lucasian professor of mathematics at Cambridge for 30 years and was one of the most distinguished mathematical physicists of his time. They remained for three hours while Hughes demonstrated all his discoveries. At the end, Hughes reported, Stokes said "that all the results could be explained by known electromagnetic induction effects, and therefore he could not accept my view of actual aërial electric waves unknown up to that time, but thought I had quite enough original matter to form a Paper on the subject to be read at the Royal Society."

Upon the publication of this account in 1899, a technical reporter visited Hughes and obtained further details; the result of this interview was also published[41] and was included by Fahie in his *History*. Hughes died a few months later and his widow returned to the United States. When she died, some 20 years later, she bequeathed her husband's notebooks to the British Museum. From them we learn that his recollection was somewhat dimmed or colored by the developments that had taken place between 1879 and 1899. What he actually assumed at the time of his experiments was that the phenomena could be explained by conduction through the air. It was with that idea that Stokes (rightly) took issue, "maintaining that the results were not due to conduction but to induction, and that the results then were not so remarkable, as he could imagine rapid changes of electric tension by induction."[42] This puts a somewhat different light on the matter—but the pity is that Hughes was discouraged altogether from going on. However, it must not be thought that he remained unappreciated. Despite the unpropitious circumstances of the visit described above, he was elected an F.R.S. a few months later. His instruments were rescued from oblivion after his death and are in the Science Museum in London.

Chance and the prepared mind

One significant feature of all these practical anticipations is that, with one exception, the scientific background of all the observers was limited. Henry, for all the intuitive genius that enabled him to discover self-induction in 1832, was probably the last electrician to make important contributions using nothing more advanced in the way of mathematics than algebra—and his guess that the action of the spark may be likened to light was in any case made long before Maxwell announced his theory. Of those who followed Maxwell, Edison was almost wholly innocent of any knowledge of theoretical physics and quickly got out of his depth when he tried to account for his observations theoretically; Elihu Thomson and Houston were science instructors in a secondary school; Dolbear and Hughes were practical men who had made important contributions to the development of the telephone, but—like Edison, E. Thomson, and Houston—more in the tradition of craftsmen and artisans than of engineers or scientists. None of them was likely to know what a partial differential equation was, let alone how to use it in interpreting a new and revolutionary theory such as Maxwell's. When one of them, Hughes, called in a group of distinguished scientists who certainly knew of Maxwell's theory and could have connected the demonstrated phenomena with it, they did not believe in such a connection—though one should recall in their defense that Maxwell's theories then still fell short of general acceptance by his peers.

For the same reason, it is small wonder that the one exception in the above group, S. P. Thompson, B.A., B.Sc., who was then at the very beginning of his career, should have likewise failed to appreciate that he might have concerned himself with something more than a mere refutation of the "etheric force." He showed that the phenomenon's nature was nothing but electric, in a piece of work that did great credit to a youth of 24; he might have insured everlasting fame for himself if he had gone a step further to speculate on the characteristics in which the effects of the spark trains differed from those of single sparks produced electrostatically. But this was his first independent investigation and he was quite pleased to have carried it as far as he had and to have been asked to present it at his debut appearance before the Physical Society in London.

So the great theory and the experimental observations remained unconnected still. The connection was not made until chance had brought together the relevant experiment and an observer whose genius was as great as Maxwell's own. "Chance," said Pasteur, "only favors prepared minds."

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Scanning the issues

When Communication Equals Transportation. One of the most fascinating of modern studies, and one with intriguing sociological implications, is the replacement of travel by communication. A short, very readable report on an ongoing study of the substitution of communication for transportation appears in a recent issue of the IEEE TRANSACTIONS ON COMMUNICATION TECHNOLOGY. The study, being conducted by an interdisciplinary group at the University of Santa Clara, Calif., seeks to identify and attack problems associated with this substitution from sociological, political, economic, psychological, and technical viewpoints.

In a certain sense, author Timothy J. Healy argues, all communications are a substitute for travel, in time if not in space. Just as the ancient signal fire replaced the news runner, so modern television has obviated the need of traveling to the football game, the political rally, and so on. Often enough, the device does more than substitute—it brings the viewer the game or other information he would not otherwise be able to see.

Today, the opportunities for effecting the substitution are becoming greater and more evident. We now have the technological capability of making major substitutions in education, shopping, medical and legal services, commerce and banking, and in employment activity. The cost of individual transportation is rising while the cost of communication is falling, and at the same time communication is becoming more sophisticated. These factors, Healy observes, mean that it is becoming more important to consider deliberately what substitutions are possible and what effect they will have on our lives.

Some activities are more amenable to substitution than others—for instance, the telephone solicitor undoubtedly can work at home; the editor, salesman, teacher, accountant, stenographer, lawyer, and engineer can probably do much of their work at home; but the fireman must certainly travel to his work. The study is going into not only suitability of substitution as far as technological feasibility is concerned, but is looking also at its economic, sociological, and psychological desirability. A mathematical decision model is being developed for the determination of feasibility in an overall sense.

As well as considering the various communications media that are available, the report looks into the ways in which substitution can be effected. For instance, in an office center, a central sales meeting or an executive board meeting can be handled through a video conference call, thus obviating long airplane trips. Two other general possibilities are to set up home remote work centers (the employee stays at home, with no commuting) and neighborhood remote work centers, where the employee can walk to a partially centralized center where he has contacts with fellow employees and where facilities connected to the central office are shared.

The study also considers types of environments in which exchanges can take place—the old city, suburbia, and the new city (places such as Reston, Va., which are committed to experiments of all kinds).

The social changes that lie ahead could be most exciting. Man's work might once again be task-oriented rather than time-oriented. The communicator–worker will pick his own working hours and his own working place just as writers, for instance, can do today. And it may become difficult to distinguish between leisure activity and work activity. There is no question, Healy says, that substitutions will be made, but the problem is to make such substitutions intelligently. There is no point in bungling the beautiful possibilities that technology offers in the communications - equals - transportation equation. (T. J. Healy, "Transportation or Communications—Some Broad Considerations," *IEEE Trans. on Communication Technology*, April 1968.)

Neural Elements and Systems. The second special issue of the PROCEEDINGS OF THE IEEE to deal with living systems has just been published—the first appeared in November 1959—and it will undoubtedly be welcomed with keen interest by many kinds of specialists. Guest editors of the special issue, which deals with studies of neural elements and neural systems, are the well-known Walter Rosenblith of M.I.T. and Thomas F. Weiss, also of M.I.T.

In a quietly authoritative preface to the long-awaited special issue, the editors lay out the questions attendant upon selecting the theme of the issue. Dealing with the nervous system as a sample living system, they note, entailed making choices that are common to all studies of living systems: Which level of biological organization was to be emphasized and how were the gaps between levels (that often find themselves reflected in the gaps between disciplines) to be bridged? In relation to the nervous system, the following levels are commonly identified: molecular, cellular, multicellular (involving organs and neural centers), and finally the behavioral level. The relevant disciplines range from molecular biology (of the biophysical and biochemical varieties) via physiology to a brand of psychology that in addition to being experimental is becoming increasingly mathematical. Actually, the editors continue, the more specific disciplinary labels often carry the prefix "neuro"; neuroanatomy, neurochemistry, neuroendocrinology, neuropharmacology, and neurophysiology are some. Other disciplines of brain research include the behavioral sciences (sometimes called neuropsychology), neurocommunications, and biophysics; and, finally, the editors remind us of how much is to be learned from an analysis of malfunction by listing brain pathology. Nor is that an exhaustive list.

In the years since 1959, the editors note that cooperation between engineers and physical scientists on the one hand and life scientists and practitioners of medicine on the other has so multiplied and differentiated that it no longer is either appropriate or possible to cover the whole biomedical waterfront. Their decision, after considering the idea of models of neuroelectric activity, was to organize the issue around neural elements and systems and to focus upon the levels that lie between the molecular and behavioral ends of the spectrum, in order to illustrate current understanding.

The knowledge that has been accumulated about neural elements and neural systems in the past two decades, the editors point out, has been catalyzed by technical advances in microphysiology, microanatomy, microelectronics, and even micrologics. In the first case, microphysiology consists of techniques for recording from and stimulating individual cells both chemically and electrically. Such techniques have become relatively routine. Detailed knowledge of the electrochemical activity of single cells together with the advance of the more classical techniques of studying populations of cells has had an impact on all levels of the study of neural elements and systems from the membrane level to the level of interactions of small numbers of cells to the level of the organization of the central nervous system of a variety of species.

In microanatomy, advances in techniques have paralleled those in microphysiology. Perhaps the single most important new tool, the editors note, has been the electron microscope, which has enabled investigators to observe with much greater resolution both intracellular structure and the details of intercellular junctions. Other techniques, such as cell-constituent identification through dye injections by microelectrode, tracing of neural pathways, and so on, have also had a deep influence on microanatomical knowledge.

In the domain of microelectronics, the availability of low-noise, high-input impedance amplifiers has made possible the recording of cellular potentials of microvolt level and millisecond duration with microelectrodes whose resistances are in the range of megohms. Also, the growth of computer technology has made a host of studies possible, and has led also to significant progress at the conceptual level.

The editors note, however, that more than novel techniques are needed to secure progress, and they point to the view that there must be developed a broad and substantial educational base if the emerging professional specialties are not to run the risk of too early obsolescence. They also observe that the National Institutes of Health and other U.S. government agencies have opened new perspectives to the engineering profession, in giving real support to the cooperation between it and the life scientists, and that they gave support at a time when the engineering profession seemed very much to be searching for such perspectives.

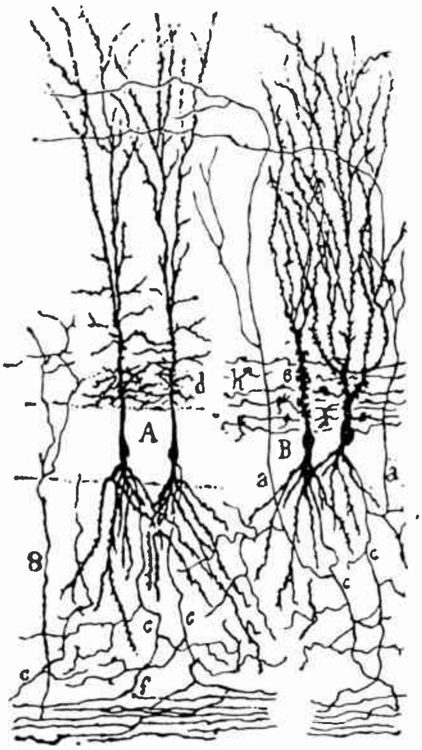
Rosenblith and Weiss warn that their observations should not be interpreted to mean that the problems of cooperation between the biomedical fields and engineering with respect to research, education, or even institutional coexistence have already been solved, but they do see productive combinations, and they regard this special issue on neural elements and systems as a modest contribution in this direction.

There are 18 papers in this special issue, four on neural elements, 12 on neural systems, and two on microelectrodes. The neural-element papers include: "Specifications for Nerve Membrane Models," by J. W. Moore; "Fluctuation Phenomena in Nerve Membrane," by A. A. Verveen and H. E. Derksen; "Synaptic Physiology," by C. F. Stevens; and "Using Electronic Circuits to Model Simple Neuroelectric Interactions," by E. R. Lewis.

The papers on neural systems take up such subjects as the cerebellar neuron network, neural coding in frog auditory systems, spike discharges in cochlear nucleus, optical filtering in the human eye, cortical motor signals in the spinal cord, and others. Electrical properties of metal and glass microelectrodes are treated in the third group of papers.

In an issue such as this, the general reader cannot help but be impressed with the utter depth of complexity of the nervous system and of the tenacity that scientists have exhibited in trying to unravel its mysteries and to map its pathways so far as is possible. One of the pioneers and foundation stones of this effort was Ramón y Cajal. His remarkable drawings, based on staining techniques, were done at the turn of the last century and still buttress modern works on neuroanatomy. One of his many drawings, presented in Fig. 1, shows the arrangement of the so-called pyramidal cells in the hippocampus of the mouse. It appears as one of the illustrations in Lennart Heimer's paper, "The Tracing of Pathways in the Central Nervous System," which offers a thumbnail history of nerve-mapping techniques that is worth the time of the general reader. (*Proc. of the IEEE*, June 1968.)

FIGURE 1. Original drawing from a Golgi section by S. Ramón y Cajal.



7.5-kVA Transient Synthesizer. A unique piece of power test equipment called a 7.5-kVA power transient synthesizer is described in the current issue of the IEEE Transactions on Instrumentation and Measurement. The device can be used to simulate transients on power systems so that the effects of such transients on electric and electronic test equipment can be studied.

The synthesizer furnishes 7.5-kVA three-phase 120/208-volt power and 5.8-kVA single-phase 120-volt 50/60-Hz power with a variety of controlled power parameter fluctuations. Output includes continuous undervoltage and overvoltage, momentary undervoltage and overvoltage lasting for 8.3 ms to 5 seconds, power outages lasting for identical durations, sine waves with superimposed pulse voltages, and square-wave and frequency-changing sinusoidal voltages.

As an example of what can be expected of the synthesizer, the author shows the reaction of several parts of a dc power supply to outages of short duration and to sudden changes in supply voltage.

The author notes that the transient susceptibility test on the dc power supply is only one of its many uses. Since the construction of this prototype model in 1966, it has been used to test the transient susceptibility of naval communication equipments, numerous dc power supplies, and EMP suppression power filters.

The first prototype is designed for transportability. It is housed in four racks, each weighing between 200 and 700 pounds. A second-generation synthesizer is under development. (H. H. Kajihara, "A 7.5-kVA Power Transient Synthesizer," *IEEE Trans. on Instrumentation and Measurement*, June 1968.)

Technical correspondence

Erratum

In the IEEE SPECTRUM June article on "Spacecraft Infrared Imaging" by John J. Horan, the text on page 74 contains several errors, including a reversed ratio and the repetition of two sentences. The text immediately after the listing of the four variables should read as follows:

"However, if the sun's energy constitutes only a very small percentage of the total reflected energy, it can be ignored and a direct measure of the self-emitted radiance from the target can be obtained. For example, it may be assumed that the ratio of emitted energy from a 200°K blackbody to reflected sunlight (50 percent albedo) in each of the window regions is only about 7.8×10^{-4} for a 3.5- to 4.2-μm window, whereas the ratio is 18 for an 8- to 13-μm window. It is therefore evident that the reflected sun energy in the former region is many times greater than the 200°K target, whereas in the 8- to 13-μm region the reverse is true. Under nighttime conditions, the available energy (radiance of a 200°K blackbody) in the 8- to 13-μm window is nearly 100 times greater than in the 3.5- to 4.2-μm window."

Comment

The autobiography of Mr. Marriott (June IEEE SPECTRUM) was a joy to read. His down-to-earth and frequently humorous remarks probably put the early "wireless" people in true perspective.

From casual reading, I had gained the impression (up to now) that the pioneers were a headstrong, contentious, grasping lot, including a few out-and-out scoundrels. Maybe this sort of thing has happened in other fields of science, but somehow I have a feeling that wireless had more than its share. That "serendipity" played a large role in many of the developments is rather obvious, e.g., "the flock of electrodes" added to the Fleming valve.

Mr. Marriott performed a real service by puncturing the pomposity of some of the veterans who have, through age, gained an aura of dignity. I can think of some names, but I won't include them here!

Eugene E. Pearson
Philadelphia, Pa.

Power-full education

In a recent IEEE SPECTRUM article,[1] Professors Erdelyi and Barnes refer to a study of a committee of the Electrical Engineering Division of the American Society for Engineering Education (ASEE), entitled "The Educational Needs of the Electrical Utility Industry." Mr. Dwon, in the same issue,[2] questions the reliability of the survey on which the committee report was based, and indicates that he believes "it to be a poorly conducted and very biased survey." Since, to the best of my knowledge, this study was never published, I feel that as chairman of the committee I should give our side of the story so that SPECTRUM readers may reach their own conclusions as to the validity of Mr. Dwon's statements.

First of all, the only specific reference from the committee study in the Erdelyi and Barnes article is on page 73: ". . . indicates that the investor-owned utilities employ yearly 1000 new engineers, only 600 of whom are electrical engineers." Apparently this was taken from page 2 of our study: "A recent survey by the Edison Electric Institute (EEI) indicates a present requirement of about 1000 engineers per year. A little over half of these will be E.E.'s. . . . Thus the investor-owned utility requirement is 500 to 600 E.E.'s per year." The committee did not survey the entire investor-owned utility industry as to manpower needs. We made use of the EEI survey. Edwin Vennard, vice president and managing director of EEI, is quoted[3] as saying: "The industry will need 5000 new engineers in the next five years." Thus it seems to me that Dwon's complaint that the survey gives an unreliable indication of needs should really be directed at the EEI survey.

Mr. Dwon further states, "I have reason to believe that the companies surveyed are mostly small ones, the type that are not known for their progressiveness, innovations, or outstanding technical achievement." Since we guaranteed anonymity to the companies responding to our survey, no listing of them can be made available. However, the following information about the 23 investor-owned companies included in the survey may prove informative.

Geographical Distribution: Northeast, 2; East Central, 5; Southeast, 1; North Central, 9; South Central, 6.

Capitalization: \$1 billion and over, 4; \$500 million to \$999 million, 1; \$100 million to \$499 million, 13; under \$100 million, 5. The total capitalization of the 23 companies was \$9.79 billion.

The companies employed a total of 2534 electrical engineers and hired 151 electrical engineers in 1964. Their estimated total requirement of new electrical engineers was 160 per year for the five-year period beginning in 1964. Thus, the utilities in this particular sample hired 94 percent of their required electrical engineers in 1964.

An indication of the sample size as compared with the total EEI group may be obtained from capitalization and electrical engineering manpower figures for 1964.

	EEI	Sample	Sample %
Capitalization, billions	\$47.3[4]	\$9.79	20.7
Yearly B.S.E.E. requirements	500–600	160	32–26.7
Total E.E.'s employed	10 200[5]	2534	24.8

I certainly would agree with Dwon that the true demand for power engineers would encompass "the whole of the greater power industry including energy producers, power apparatus manufacturers, [and] large users of electric energy." We considered such a survey early in our study, but the magnitude of the task overwhelmed us. (We were given no financial support whatsoever for the survey.) For instance, the Federal Power Commission[6] indicates that there are 3600 electric power systems in the nation. When one adds apparatus manufacturers, consulting firms, and users to the list, it becomes large indeed. If, as Dwon states, several members of the IEEE Power Engineering Education Committee challenged our survey (no member of this committee has seen fit to communicate any such challenge to me), then I respectfully suggest that such a survey of the greater power industry would be a worthwhile project for the committee.

Finally, if I interpret Dwon's statements correctly, he feels that our survey was biased because the utilities included were able to hire a very large percentage of their electrical engineering requirements in 1964. The concept that an electric utility is measured for "progressiveness, innovations, or outstanding technical achievements," by its inability to recruit an adequate number of electrical engineers is a novel one. In fact, according to Dwon's own statement,[2] his company—The American Electric Power Service Corporation—obtained its quota of electrical engineers in 1964, and thus enjoyed recruiting success comparable to our sample. It is my personal opinion that if our sample was biased, it was biased in exactly the opposite direction than Dwon contends it was, and possibly included too high a percentage of large and progressive utilities.

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The opinions contained in "Feedback from the Field," however positive or negative, are most welcome. At last a discussion has started that may, in the future, bridge the wide gap between the universities and the electric utilities. As one of the authors of the original paper, I welcome the publication of my answer to these discussions.

I would like to express my thanks to Prof. W. A. Lewis for his positive comments.

Mr. Cozzens' contribution is encouraging. As a leading officer of the APPA, he has enlarged upon the difficulties of attracting high-school graduates to choose engineering as a career. It is good to note that he is satisfied with the existing curriculum of undergraduate education of electrical engineers. His opinions on employing students at utilities are very useful.

His views on funding are more difficult to accept. Nowadays the federal government is called upon to foot the bills of many programs, and now, he recommends, it should also provide the additional funds necessary for the education and research expenditures of electric power system engineers. Other utilities (telephone, gas, water, etc.) would then demand the same support. This would mean increased taxes—a political problem. Such measures would require more political support to get through the Congress than universities or the utilities could marshall.

A user's contribution, suggested in the article, is not without precedence. Most of the turnpikes collect a user's toll. Gasoline taxes are imposed on the motoring public to provide road funds. In the final analysis, the discrepancy between the authors and Mr. Cozzens can be reduced to this question: Should taxes be increased or should utility companies add an infinitesimal fraction to their bills and thus provide an educational fund? It does appear that the collection of these funds and their proper distribution could be made most efficiently by the utility companies.

It is rather unpleasant to deal with Mr. Dwon's contribution to the feedback. He uses a device of "summarizing" the contents of the article to fulfill his requirements, and then carrying out a polemic against his own "summary." This is clearly seen from his statement: "Erdelyi and Barnes primarily suggest a method of supporting campus research." Research topics are discussed only in half a page of our six-page paper; only \$500 000 out of \$4 million have been suggested for research. Mr. Dwon's contentions must therefore be examined in detail.

One would expect Mr. Dwon, as a utility executive, to be businesslike and also report how much the utilities spend on supporting electrical engineering education. He has tabulated 16 universities with programs that are of interest to utilities. Information has been gathered from the administration of these universities in order to learn the size of the supports. Thirteen of the universities have readily given information. An analysis of the reports has shown that only two of these schools receive support in excess of \$50 000 per year. Several schools obtained less than \$2000 per year. The average support per year, per institution, was (in round figures) \$28 000. It was rather surprising and disappointing to learn that one of the best-known graduate schools receives only \$37 000 in the average year, of which \$28 500 is allotted to equipment. The faculty and students of that school receive only \$8500 in the average year.

In the light of these figures, one arrives at the conclusion that the electric utilities support electrical engineering education with an amount well below \$500 000 a year—only one eighth of the funds that we consider necessary for this purpose.

A report, which was issued after this letter was written by the Edison Electric Institute, entitled "Engineering Manpower Needs of the Investor-Owned Electric Utility Industry," indicates that the utilities spent \$480 000 in 1966 in support of higher education, with \$486 550 for research. It is our feeling that, although these figures are approximately those that we recommended in our article, the distribution is now such that the utilities are not getting the results necessary to cure the problems we described. Significant sums will have to be added in the areas we indicated if the present situation is to improve.

Mr. Dwon doubts the reliability of the ASEE survey, which is Ref. 7 of our article. This is surprising, because it agrees with the results of the study of Prof. E. Greenfield (Ref. 10 of the paper).

Mr. Dwon also states that his company has no difficulty obtaining its quota of engineers, and follows up with the statement that AEP needed 19 young recruits and were able to get 13. Is there not a wealth of evidence that the present plans for supporting electrical education fail to provide the necessary engineer power for the utilities? If there is no shortage, why do some companies send recruiters to Scandinavian countries? The Swedes feel just as strongly about brain drain as the British.

Our article did not propose a centralized research program. On the contrary, it was suggested that "the specialized senior-year student program and the graduate research program be established regionally by joint planning between the selected universities and the neighboring utility companies."

Mr. Dwon assures us that AEP would not support the concept of our article. I had the good fortune of receiving information about how other utilities think of the concept. A director of training at a large privately owned southeastern utility wrote: "The general consensus of those who read the paper is that it is a good paper and a sound plan."

A chief engineer of a large privately owned eastern supply company writes: "It seems to me that you have stated very well a point of view which needs to be recognized in reaching a thorough practical understanding of the problem which must be solved cooperatively between the universities and the public utility industry."

The manager of engineering of a southwestern utility writes: "I feel that your procedure and your program is very good and I personally don't see why it can't work."

A supervising engineer of the largest western utility wrote:

"... your observations are well taken regarding research by universities, the most opportune time to interest undergraduates, the suggested conditional scholarship program, and the suggestion that the EEI participate in an organized large-scale program for the benefit of utility engineering education."

The good image that is so fervently sought by the electric utilities can be obtained by cooperation. It would be desirable to hear clearly from EEI and APPA. The utilities will have to decide if they will follow the lead of the oil companies, or repeat the fatal mistakes made by the railroads several decades ago.

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Another crisis?

I am still visibly shaken by C. K. Gordon's "The Third Great Crisis in Mathematics" (May IEEE SPECTRUM), and particularly by his sun- (if not earth-) shaking statement of the Banach–Tarski paradox, in which the sun and a pea are offered as examples.

In a sincere attempt to resolve this impasse, I am willing to offer my patented solar knife to cut up the sun into the little solid (or gaseous) pieces that are stipulated. As in the case of the Balonski–Salam paradox, however, I fear that the axiom of choice will inevitably prove to be: "No matter how you slice it—it's still baloney."

John Chandos
White Plains, N.Y.

P.S. I am also willing to supply the pea, on request. *J.C.*

Reader Chandos should retain his pea until he has digested "Sur la décomposition des ensembles de points en partie respectivement congruentes," by S. Banach and A. Tarski, cited in Gordon's bibliography.

Editor

Source revealed

Some readers may be interested in learning that the statement, "By studying the masters, not their pupils," (C. K. Gordon, Jr., "The Third Great Crisis in Mathematics," May IEEE SPECTRUM, p. 52) is attributed to the great mathematician N. Abel (1802–1829).

Anyone interested in pursuing the matter is referred to *Men of Mathematics*, which is a magnificent collection of biographical sketches by Eric Temple Bell.

Jose R. Martinez
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A clearer focus

In the September 1967 issue of IEEE SPECTRUM, R. Kompfner lists M. Knoll and E. Ruska among the scientists who made major contributions to electronics by developing the electron microscope.[1] He advocates new prizes for achievements in engineering, comparable in stature and importance to the Nobel Prize, and recommends Ruska as one of the prospective recipients of such a prize for his invention of the electron microscope.

In the March 1968 issue of IEEE SPECTRUM, G. W. Hoffman states: "Although E. Ruska was a major contributor to the development of the electron microscope, he was not its inventor. . . ."[2] He claims that the inventor was Dr. R. Rüdenberg. This claim can only be based on the priority of Rüdenberg's application for a German patent on May 31, 1931. (This application led to three German patents and three non-German patents based on the German priority. Within the next year, Rüdenberg filed German applications, which led, together with the original application, to four German patents and four non-German patents. An additional German patent was filed on August 13, 1932, after the expiration of the original German priority. For details see Ref. 3.)

However, by early 1931, as I have shown in my paper, "Origin of the Electron Microscope,"[3] M. Knoll and E. Ruska had already reduced to practice the teachings of Rüdenberg's patent disclosure. Since 1928, they had conducted painstaking experiments on the magnetic coil—the focusing coil of the cathode-ray oscillograph. The results were published in 1931 (see Ref. 4).

Based on this research, they had built an electron microscope consisting of two magnetic lenses with an intermediate image. From February 1931 on, they had demonstrated this device to many interested scientists. Knoll gave a public lecture at the Berlin Institute of Technology on June 4, 1931, only four days after Rüdenberg's application. At this lecture, he showed pictures of the device and of the images obtained with it. It was followed by a comprehensive paper on electron optics that was submitted for publication on September 10, 1931, and published early in 1932.[5]

This paper described, among other things, the experimental setup and showed, for the first time in print, images, not of the usual round apertures, but of T-shaped apertures and of metal meshes. The magnification was approximately 17X.

The next paper, entitled "The Electron Microscope," which was submitted in June 1932 and published later that year, showed magnifications of 150X and reported on 400X.[6] In another paper, published in 1934, Ruska was able to show magnifications of 8000X and 12 000X, surpassing for the first time the resolution of optical microscopes.[7]

In contrast to this, the two Rüdenberg papers cited by Hoffman do not describe any experiments or any equipment. The first one,[8] a short letter to *Naturwissenschaften*, dated June 7, 1932, was published in the same year. It does not give any technical information whatsoever.

The second one,[9] published in 1943, essentially describes the American patents, which were based on the 1931 German priorities.

Without Knoll and Ruska, the electron microscope would not have been developed at that time. Many features of today's sophisticated electron microscopes were first developed by them. With due respect for the late Dr. Rüdenberg, for whom I have a high regard, I submit that he did not contribute to the development of the early electron microscopes.

In the light of this, it appears incomprehensible that Hoffman should object to Kompfner's recognition of Knoll and Ruska as the originators of the electron microscope.

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Here is the opinion of two distinguished participants in the development of electron optics.

In 1957, Dennis Gabor wrote: "From the *standpoint of patent law* [Gabor's emphasis], Reinhold Rüdenberg is the inventor of the electron microscope. . . . From the viewpoint of success, greatest recognition should go to Max Knoll, Ernst Ruska, Bodo v. Borries, and Ladislas Marton."[1] In a monograph that has been just published, L. Marton says: "Legally, Rüdenberg is the inventor of the electron microscope, because the patent documents on file say so. Practically, the electron microscope is the creation of a number of people, and a few names stand out."[2]

Whether Rüdenberg could have contributed to the development of the microscope if he had not been forced to leave his post in Germany remains a moot question. (After World War II, his firm, Siemens, having become the world's leading manufacturer of electron microscopes, made handsome restitution to him.) Certainly Kompfner and Gabor, themselves exiled by the Nazi ascendancy, can hardly be accused of prejudice against Rüdenberg.

This correspondence is now closed.

Editor

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Dissent

The article, "Game-Theoretic Applications" by James P. Dix, which appeared in the April 1968 IEEE SPECTRUM, was a most disturbing piece of work on several counts.

First of all, the article was extremely difficult to follow because the example used specialized vocabulary, *ad hoc* procedures, and results relevant only to the specifics of the air defense problem, not game theory.

Furthermore, since the example was drawn from a classified area, the author could write, "I cannot go into great detail about the system since much of it is still classified," and dash about from topic area to topic area with great abandon. Equations arise mysteriously, to be explained by "use of the symbolism is not intended to confuse the reader, but merely to indicate that a mathematical method exists, and that because of this, certain computer methods are necessary to solve them."

Aside from an inane final paragraph concerning chess-playing programs, the most serious technical objection to this article is that the zero-sum assumption is mentioned only briefly in Eq. (1), with no hint given as to the philosophical importance of this assumption to the overall air defense analysis. The SPECTRUM reader should have been told about the critical nature of this assumption, or have been referred to a source such as Ref. 1. As it is, the author has not seen fit to provide *any* references or bibliography for his most inadequate treatment of the subject.

Oscar Firschein
Lockheed Missiles & Space Company
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