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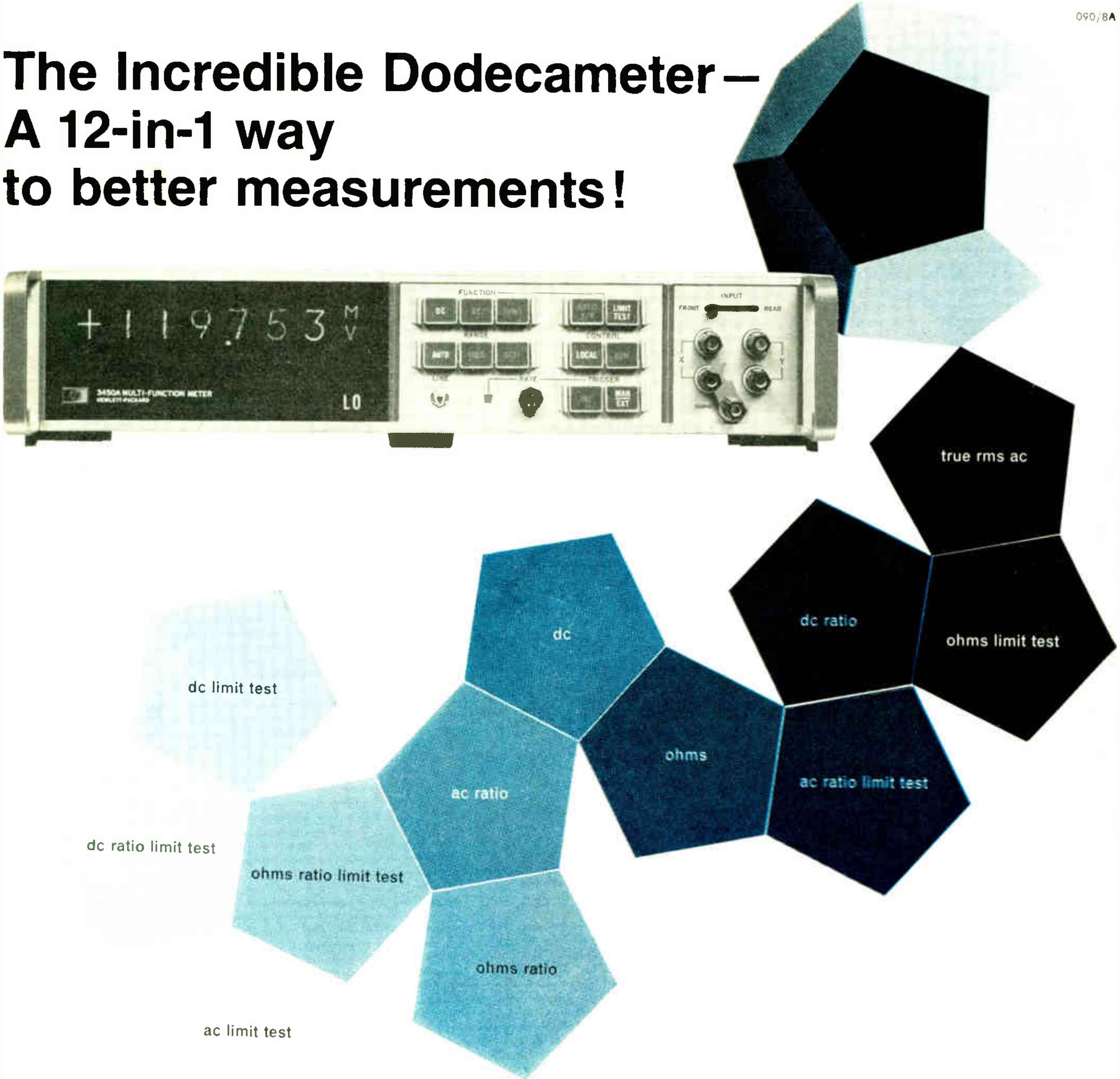

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DIGITAL VOLTMETERS

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the cover

Looking like an ultramodern lighthouse, the control tower, or "cab," at LaGuardia Airport (New York terminal area) appropriately sets the introductory scene to Part I of a three-installment series on air-traffic control, beginning on page 26

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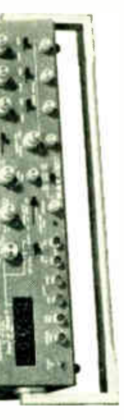

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Forum

Readers are invited to comment in this department on material previously published in IEEE SPECTRUM; on the policies and operations of the IEEE; and on technical, economic, or social matters of interest to the electrical and electronics engineering profession.

Conversion and imports

Under the title "Conversion and the Import Problem: A Confluence of Opportunities" (*IEEE Spectrum*, April 1970), J. E. Ullmann presented an interesting article on the conversion of the military electronics industry to civilian products, and on the need to consider competition from other nations. The author's thesis, although it is applied to the United States, is a more general one since competition among nations must be faced no matter where an industry is located. Professor Ullmann suggests that government support of research on materials and processes for nonmilitary products will help. It seems to me that there are shortcomings to such a solution, which make other methods worthy of consideration. One of the major causes for foreign dominance is a lower labor pay rate or, more correctly, higher productivity per labor dollar. Fundamentally, production costs ultimately depend on labor costs; even completely automated production requires labor to make and to maintain the production machinery.

The obvious long-range result of differences in labor costs between different areas of the world is a closer approach to equilibrium; i.e., more is done in the low-cost area and less is done in the high-cost area until the situation balances across whatever barriers exist. Equilibrium, however, does not imply equality, and it is unlikely that equality of productivity per dollar will exist among nations any more than it does among individuals. Among the factors or barriers that may lead to an equilibrium *that is not equality* are

1. Customs and protective tariffs.
2. Availability and costs of raw material and power.
3. Skills and training of labor and management.
4. Inequality of innovation and invention.
5. Transportation costs of raw materials and finished products.

Customs and tariffs have a bad name, just as do other forms of taxation. Nevertheless, they can be used as a fast-acting and flexible adjustment to achieve desirable goals. This barrier can be used for "fine tuning" international economics and trade, but it has so many political overtones that no general remarks can be made about its specific value in electronics. If (as in electronics) raw material and power costs are not a large factor or are not widely different, our attention must be confined to factors 3, 4, and 5.

The proposal by Professor Ullmann, namely, a government subsidy in the form of a National Technology Foundation, is addressed to the United States and proposes to increase factor 3 and, to a lesser extent, 4. In any country, if such a sponsored work is successful, improved skills in automation and manufacturing technology can favor production in that country. However, knowledge has a transportation cost very close to zero. Thus, if some one country has the equivalent of such a subsidy now, as implied by Professor Ullmann for Japan, other countries ought to be able to copy without the subsidy. The one advantage the originating country retains is the time delay before the knowledge is assimilated elsewhere.

Similar remarks apply to factor 4. For example, it is generally recognized that Japan has not made the major inventions (radio, transistor, tape recorder, television) from which it now profits so handsomely.[1] The time delay was significant but, ultimately, the ease with which knowledge is passed on indicates that the United States government subsidy for science and engineering innovation between 1950 and 1960 was only a temporary advantage to indigenous manufacture.

In my opinion, much more attention should be given to barrier 5, the cost of transporting materials and products. Consumer electronics well illustrates this effect. For example, small radios and portable television sets are items in which overseas manufacture competes well with, or even overwhelms, U.S. manufacture. Imports of console television or console phonographs, on the other hand, are minor. Thus, new products of heavy and bulky character are automatically favored for production in the country that uses them. It seems to me that this is the best approach for a country to take to maintain its own productivity. In the case of the automobile, foreign imports have not been significantly competitive with standard-size U.S. cars. There is much doubt whether imports can retain a large share of the very small car field if U.S. manufacturers decide to concentrate there.

One may become concerned about any foreign production of goods because of a possible effect on employment. It has been pointed out that almost all the increase in employment over the past few decades in the U.S. has been in services.[2] It is predicted that, by 1980, services will account for two thirds of all jobs. Services are not readily transported, and any advanced country may anticipate continued high employment so long as the currency import/export balance is maintained.

Professor Ullmann's article places its emphasis on using one form of government subsidy to retain as much manufacture as possible in the country of use. A complete picture requires consideration of other factors—for instance, a company converting from military to civilian products could well have a transportation-cost barrier that restricts imports. Such a company would hardly need a National Technology Foundation.

E. W. Herold
RCA Corporation
Princeton, N.J.

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[1] See, for example, Boffey, P. M., "Japan III: Industrial research struggles to close the 'gap'," *Science*, vol. 167, pp. 264–267, Jan. 16, 1970.

[2] Burck, G., *Fortune*, p. 87, Mar. 1970.

Dr. Herold defines some very complex problems but I fear I must disagree with some of his answers. First, production costs do *not* ultimately depend only on labor costs, whether direct or at one remove. In the Ameri-

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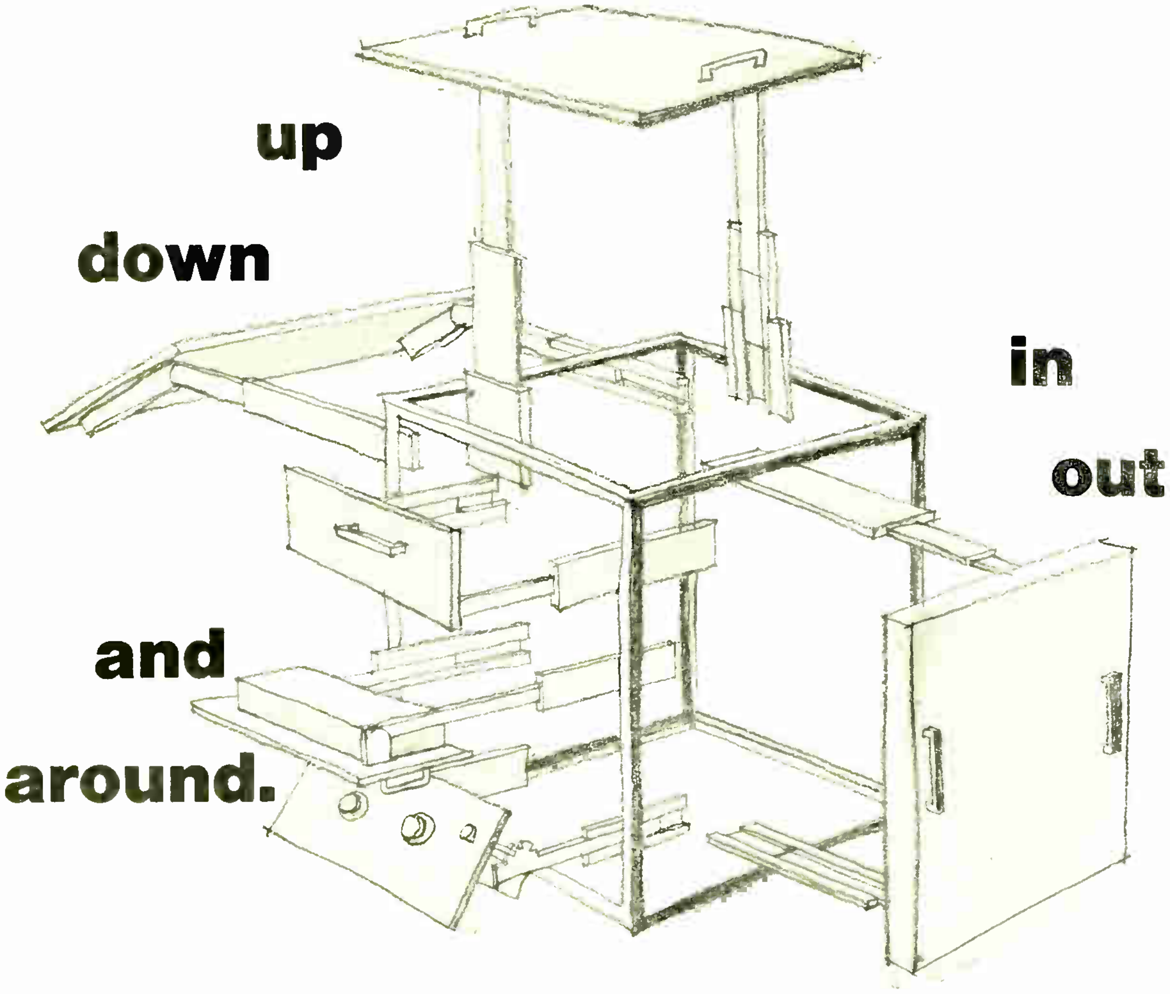

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can experience, the precipitous rise in administrative overhead, including proliferating staff functions, heavy advertising, etc. has been a major cause of the cost barriers that now face our exports—to say nothing of war-caused inflation.

If Dr. Herold thinks of the time lag as the main advantage of the NTF, that was exactly my point. An ongoing program, geared to our cost conditions, would, if done right, always be a jump ahead of the others. Japan's achievement is in production engineering rather than invention, a point I made clear. Hopefully, the current direction of our technical effort and the miseducation of our engineers are not irreversible—but I must admit to some doubts myself.

Dr. Herold's suggestion that we should literally concentrate on the heavy stuff is surely inappropriate in an industry that keeps on miniaturizing its products. When large, light solid-state television screens are a reality, who will want consoles? Weren't those power turbines that New York State has just bought from Hitachi pretty heavy? Anyway, a market redoubt based on weight is unstable. Labor costs in the U.S. have been rising faster than transportation costs so that the area in which a given firm enjoys a market advantage relative to a more efficient competitor has tended to shrink. (For details, see J. E. Ullmann and S. E. Gluck, *Manufacturing Management: An Overview.* New York: Holt, 1969, pp. 45–46.)

Finally, service employment is no salvation. We are becoming less self-sufficient all the time and we have dissipated most of our reserves in overseas military expenditures. Hence we must continue to export, i.e., produce what we can sell in foreign countries. Nor is this the only problem with reliance on service employment. (For a detailed discussion see my article, "Automation and the price of progress," *Am. J. Orthopsychiatry,* vol. 36, pp. 70–76, Jan. 1966.)

John E. Ullmann
Hofstra University
Hempstead, N.Y.

Patents

Mr. Rines, in his article entitled "A Plea for a Proper Balance of Proprietary Rights" (April Spectrum), argues that the United States should follow Germany, Sweden, the Netherlands, and Japan in declaring illegal employment contracts giving employers, in return for salary alone, title to inventions made by their employees. Mr. Rines proposes that ownership of the invention remain with the employee, the employer acquiring only a royalty-free license. Should the employer want complete ownership of the invention, he would have to buy out the employee's rights.

There is no doubt that in the countries mentioned by Mr. Rines, the employee–inventor has a greater stake in his invention than he would have in the United States. On the other hand, these countries are not as generous as the U.S. in granting patents. The "standard of invention" applied by their patent examiners is higher than ours. An application, after allowance but before final grant, is published and may be opposed by interested parties. When the patent is finally granted, an interested party may start a cancellation proceeding on the basis of newly discovered prior art. Taxes are imposed annually to maintain patents in force. The law provides for compulsory licensing.

Opposition and cancellation procedures go a long way toward filtering out the trash. Such procedures, incidentally, were proposed by the Presidential Commission on Patents and vociferously opposed by the Bar.

The cost of proving the invalidity of a worthless patent, although involving only a few thousand dollars in a cancellation proceeding before the Patent Office, runs easily to $100 000 in our Federal Courts where complicated technical questions have to be decided by technically untrained judges. The individual holder of an invalid patent and his determined attorney (often on a contingency fee) can thus extract undeserved settlements out of industry. Unless our system is thoroughly overhauled in this respect and approaches the German system, spreading the ownership of patents into the hands of individual inventors (an unavoidable consequence of Mr. Rines' proposal) would be a disaster. By making patents harder to get and giving the employee–inventor a greater interest in his invention, Germany, Sweden, Japan, and the Netherlands may have achieved what Mr. Rines' title calls "a proper balance of proprietary rights." We have also achieved some sort of balance in the U.S. But merely grafting a single feature of the German system, without other offsetting features, would only succeed in upsetting it.

J. C. Chognard
Palo Alto, Calif.

The article by Robert H. Rines, "A Plea for a Proper Balance of Proprietary Rights" in the April issue of *IEEE Spectrum*, requires comments. His basic thesis is that it is unfair for companies to require applicants for positions to sign over to the company their rights to future inventions, especially for employees who are not paid specifically to invent.

The reason for the U.S. patent system was to *benefit society* by encouraging inventors to disclose their inventions, by giving them a temporary monopoly. The original intent was not primarily to benefit inventors.

Some engineers are hired specifically to invent but, for most of them, inventions are fallouts of their normal engineering activities and of the effort to improve constantly on a product. Very few products reach the market without predictable obsolescence; if this were not so, the engineer would have learned little in the course of developing the product.

It is unrealistic to compare the present time with the nostalgic past when "attic" inventors gave us such basic and spontaneously inspired inventions as the phonograph, telephone, and the amplifying vacuum tube. The need for these was immediately apparent and the inventor did not lack the means of exploiting them. Today the reduction of an idea to practicable and salable form is beyond the means of independent inventors. Even the recognition that an idea is new and useful is confused by the rapid proliferation of the prior art and the simultaneous effort of competing companies. However, the independent inventor is not prevented, except by lack of means, from protecting his invention.

Large research organizations make many discoveries and inventions that never see commercial exploitation because they are not timely, necessary, or profitable. Such large organizations exist because they can afford ten failures for each success whereas the private inventor cannot afford this.

In industry, research and invention are often team efforts with much cross-fertilization of ideas among fellow employees. Each team requires theoreticians, experimenters, and direction, so that the credit for invention is often blurred. Even the clerk who makes an invention is probably triggered-off by contact with more knowledgeable fellow employees. If the clerk retained the rights to his invention he could, as Mr. Rines points out, "peddle his invention to a competitor."

I believe that the prospective employee loses little by assigning future unmade inventions to his prospective employer. He gains the company of others with whom he can share common problems. If he makes an invention, the patent is in his name. He gains recognition in his profession and company. His rise in both is promoted. Some companies give monetary rewards for inventions. In some countries, the invention is in the name of the employer's company and he remains anonymous.

Contrary to what Mr. Rines claims, there is little evidence that the United States has suffered in creativity in comparison with other countries. The important inventions of our times have been largely made in the U.S. The writer is mostly familiar with the fields of color television (in which at least ten companies pooled their resources to achieve a desirable set of standards), avionics, computers, and solid-state devices. The basic inventions in all of them were largely made in the United States. I attribute this creativity largely to the vast means made available for invention by private companies. The funds available for invention, research, and product improvement per engineer are far superior to those available in Europe.

The writer is an independent consulting engineer who, until retirement from a private company, had been associated with companies which promoted and encouraged invention. My own modest contribution of 30 U.S. patents was made while so employed. Since leaving these companies, I have made inventions in their fields of interest, but the cost of preparing a patent application is large enough to make the investment have a questionable return. However, my previous inventions, publications, and professional recognition have facilitated the acquisition of clients.

It does seem to me that the independent inventor would be helped if the U.S. Patent Office were to adopt the "provisional application" practice used in Great Britain. This allows an inventor to submit an invention in relatively informal form and protect the date of conception for one year. This should be adopted because it is often difficult for an independent consultant to have his ideas "witnessed and understood" by one skilled in the art who is not also an employee of an interested firm.

Finally, I do agree that an inventor who makes an invention which is completely outside the field of interest of his employer should retain rights to that invention. Thus, the engineer who works for a company that makes color television sets and who invents a portable parking space should retain full rights to his invention.

Charles J. Hirsch
Consulting Engineer
Princeton, N.J.

Industry and the universities

In the April issue of *Spectrum*, Professor Van Valkenburg makes an eloquent case for help by industry in supplying much-needed equipment to universities, and suggests that the IEEE could serve a function as the clearinghouse or information bank for lists of equipment available and equipment desired.

An even bigger role for the IEEE is to provide leadership for full-fledged cooperation between universities and industry in all areas of common interest. Thus the same rapid advances in technology that necessitate new equipment in the universities also make it imperative for industry to ask for continuing educational facilities for its members. The need for such continuing education is generally recognized, but industry has not made a serious effort to interest the universities in it, nor have the universities gone out of their way to provide it. The IEEE, through its Educational Activities Board, could encourage both parties to formulate a program of mutual assistance, in which each party supplies its "products" to the other. Such a program has a greater chance of success than one-sided help by one party to the other.

I hope that Professor Van Valkenburg's letter serves as a catalyst for action by all three groups involved—universities, industry, and the IEEE. But it is up to the IEEE to bring us (the other two) together.

S. H. Durrani
Olney, Md.

Social engineering

Political issues would be inappropriate for the IEEE, an international organization, but engineers should become more involved in social and economic problems. They have a clear duty to expose fraudulent claims made in the name of science. The most notorious group of alchemists are the "social scientists," who by and large have labeled themselves "social engineers," and throughout the last 20 years have controlled government agencies naively set up to curb social problems. The present difficulties in education, welfare, and crime are largely of their creation. The premises they espouse must be exposed logically and the liturgy of their religion exposed scientifically. If we wish to remain civilized, the cults of tribalism and communalism will have to be shown as being tribal and communal.

If the present levels of population are to be supported, many engineering problems will have to be solved. Having witch doctors from the various departments of social science preside over these problems will only introduce unacceptable delays. For engineers who wish to do something about it, I believe two novels by Ayn Rand will do much to clear the fog. They are *Atlas Shrugged* and *The Fountainhead*.

We must use science and logic to save the world for ourselves and our children.

J. M. Green, P.E.
Edmonton, Alta., Canada

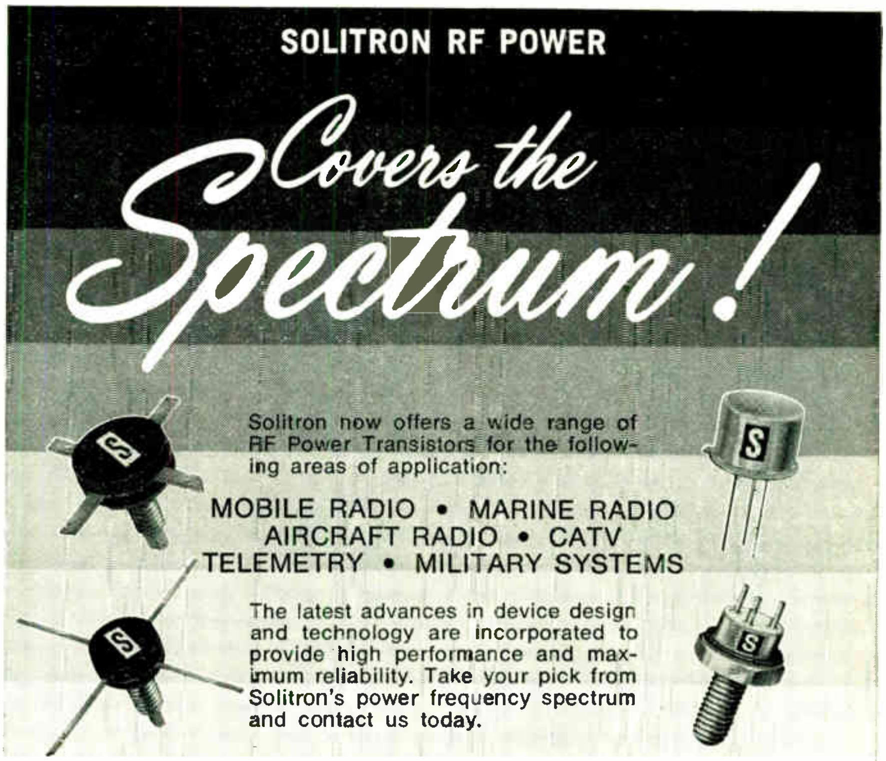
Corrections

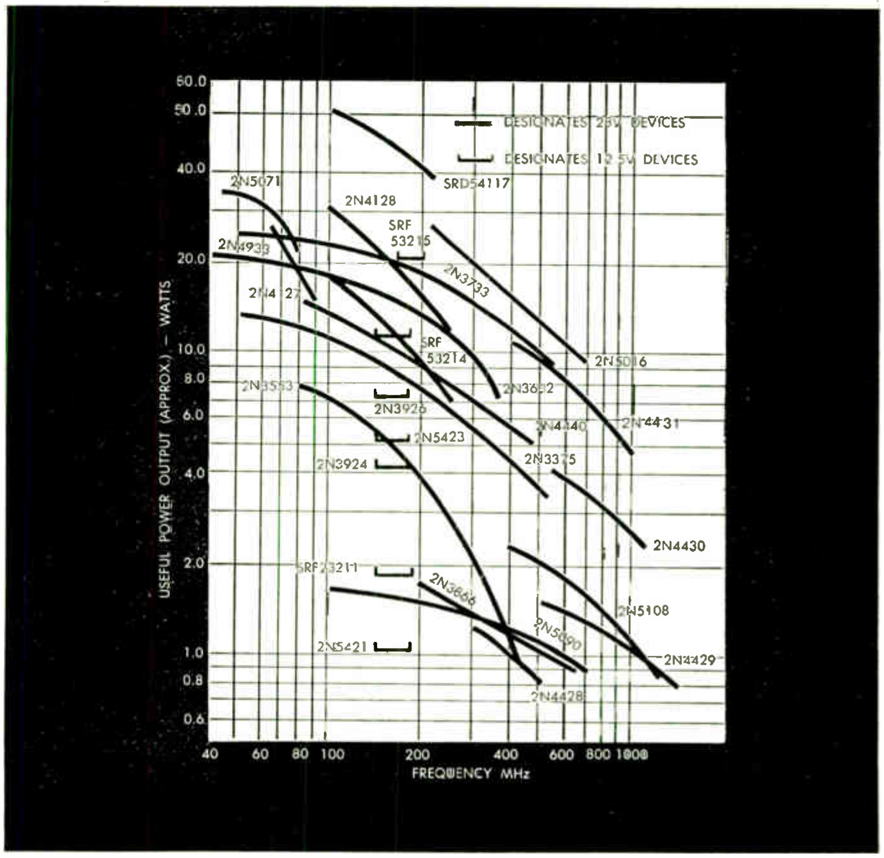
In my letter published in Forum, April 1970, page 6, I made an error. The sentence under the diagram should read:

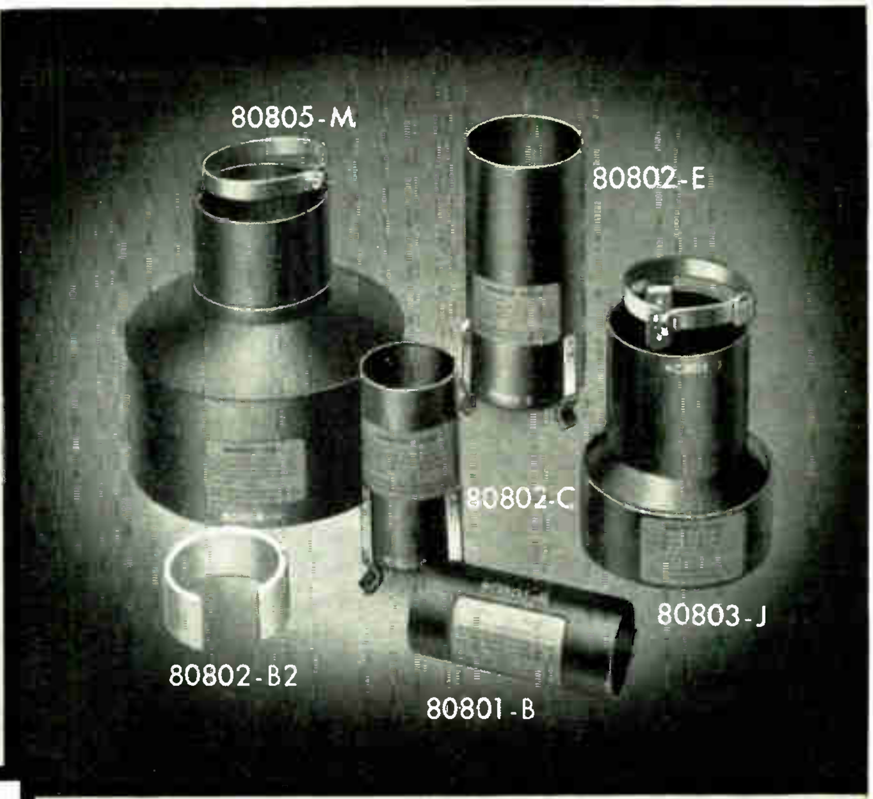
With pegs *I* and *V* set equidistant from *C*, and *O* set to give *OC* = (1/*r*) *CI*, where *r* satisfies . . .

A. G. Benedict
Minnetonka, Minn.

It has been disclosed that Figure 9 (p. 28) of Don Kesner's April article, "Monolithic voltage regulators," contains an error. The transistor should be corrected to read 2N2221.



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Spectral lines

Convention progress. Most readers of this column probably did not attend the March IEEE International Convention in New York. However, if they looked at the technical program in any detail, they noticed that it was the best one in many years. Those who attended found the performance even better than the promise; the caliber of the presented papers and the new subject matter disclosed was outstanding. The exhibits at the Coliseum, although down in quantity, were up in quality. The same remark could be made about the registration; attendance was affected adversely by deterioration of economic conditions and by the airline slowdown that began the same week, but those who did come were more serious and involved than their counterparts in years of prosperity and rapid growth.

Even the "Talk of the Town" columnist of the *New Yorker* magazine was impressed and devoted a page and a half of his delightful whimsy to our Convention (April 11 issue). The speakers at the technical meetings were characterized as "speaking a language all their own that was rather restful to listen to." (Have we invented something here—electronic sleep?) One of the Film Theater presentations, prepared by the Atomic Energy Commission, was described as: "Great color. Great camerawork. Great plot . . . . no phony baloney like 'Midnight Cowboy.' Best movie we've seen since 'Wild Strawberries.'" Now aren't you sorry you weren't there?

Superficially, the 1970 Convention showed many similarities to those of prior years. It was still in New York at the Coliseum and the Hilton, prices were even more exorbitant, crowds continued to be frustrating, and the week was so packed with organized activity that forced choices had to be made every hour. Perhaps there is no remedy for these conditions, but there are always lingering suspicions that maybe things could be better, that maybe the Convention isn't providing all that is most important to Institute members.

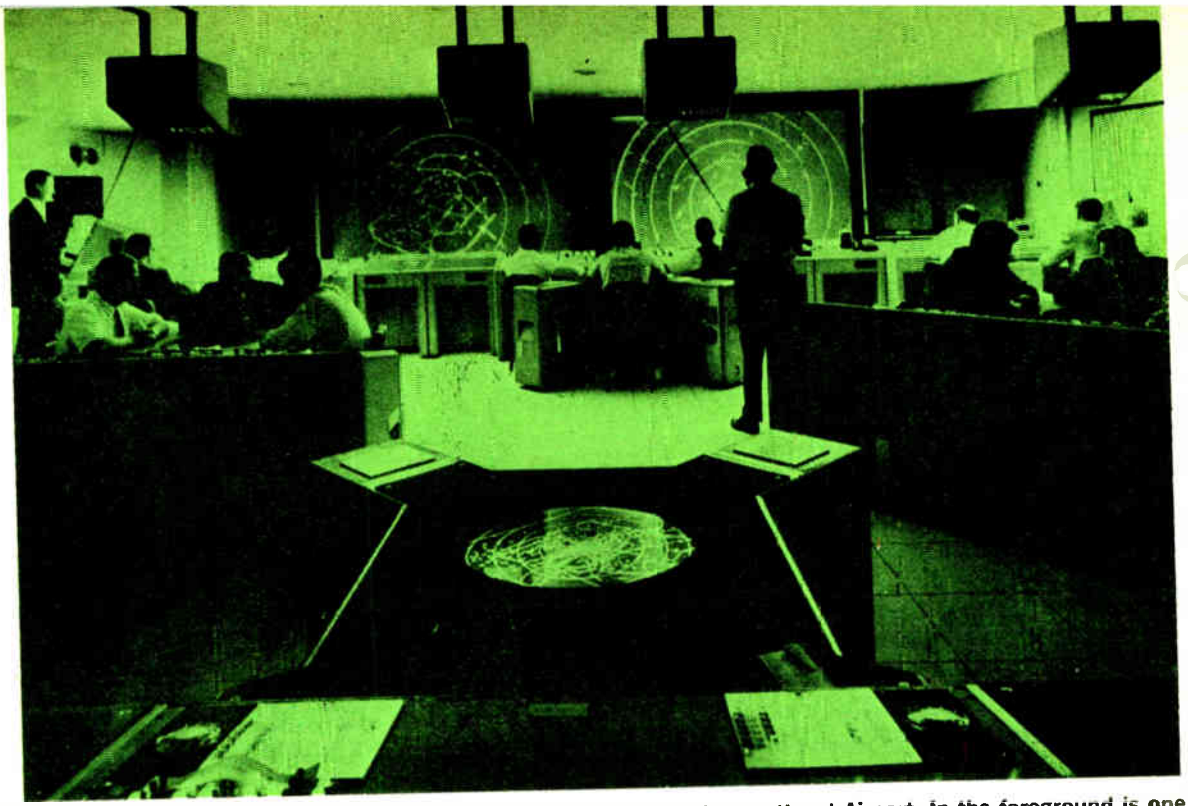
As a result of such suspicions, the IEEE Board of Directors has appointed a new Conference Board, whose responsibility is to formulate and direct improved policies for the International Convention, and also to help other conferences achieve maximum benefits for the IEEE. The Conference Board consists of six members, each to serve three years, and appointed in two parallel ladders. One of the two new members each year will be exhibits-oriented, and the other will be technical-activities-oriented. The entire Board decides on policy but, each year, there is a three-man Executive Committee that directs the Convention for that year. The succession, from newly appointed member through the steps of Executive Committee membership to Chairman of the Board and Chairman of the Executive Committee, is automatic and provides both continuity and experience. One of the questions often asked is why the name "Conference Board" was chosen instead of "Convention Board." This choice was dictated by the long-range view, which is that the Board should be open to help IEEE with more than the International Convention. For the next year or two, primary attention will be given to the Convention, since this is the most important single conference we hold. Beyond this, however, it should be possible to do a better job in coordinating and planning all conferences, and the Conference Board will assist any group that wants or needs help in this area.

To work with the Conference Board there is a new Headquarters staff organization, headed by an experienced Director of Convention and Exhibits Services. Since he can also call on other Headquarters people who have had experience with past Conventions, the IEEE should have everything to gain. Both the Conference Board and the Headquarters staff are planning innovations in every Convention activity for which they come up with an idea for improvement. If members want to contribute suggestions, they will probably get more personal attention and consideration than ever before.

If the writer can be forgiven for a suggestion of his own, he feels that there is both the need and the possibility to improve conditions for person-to-person contact. The November 1966 special issue of *American Psychologist* devoted itself entirely to reviews and surveys of how scientists and engineers communicate. Several papers, and the references cited, gave a clear-cut indication that personal and informal contacts are far more important than is generally believed by enthusiasts for formal publication. This situation is particularly true among engineers. In one quoted study (T. J. Allen in the *Industrial Management Review*, vol. 8, pp. 87–98, Fall 1966), engineers and research scientists were compared as to how they derived their ideas during some typical projects. The study indicated that 51 percent of the ideas in the science research projects came from the published literature. For the engineering programs, only 8 percent came about in this way, whereas 48 percent were the result of contacts, of which many were personal (customers, vendors, colleague engineers, and outside sources). During the IEEE International Convention, the exhibit area provides opportunities for personal contact but places where one can sit down for a quiet chat are lacking. At the Hilton, the environment is better, but the formally organized technical sessions provide little opportunity for man-to-man contact. It ought to be possible to improve matters at both ends.

All in all, IEEE has a great opportunity to make future Conventions even better than the one just past. It will be exciting to see if we can impress the sophisticated *New Yorker* magazine another time.

E. W. Herold, Editorial Board



GENERAL VIEW of New York's Common IFR Room at Kennedy International Airport. In the foreground is one of the control consoles; on the far wall may be seen the two large-scale screen display projections of the New York terminal area airspace. The personnel in the picture are controllers and supervisors.

At the crossroads in air-traffic control

I. The view from the ground—the congested airports; the Common IFR Room; present and future automated systems; plans of the FAA; problems of the air-traffic controllers

Flight operations (takeoffs and landings) at the major airports in the U.S. have increased from 30 to 50 percent since 1965, and the trend in operations is upward. In Chicago, Cleveland, Los Angeles, Oakland, Washington, and in the New York City area, the common situation of overcrowded airspace is particularly acute

Gordon D. Friedlander Staff Writer

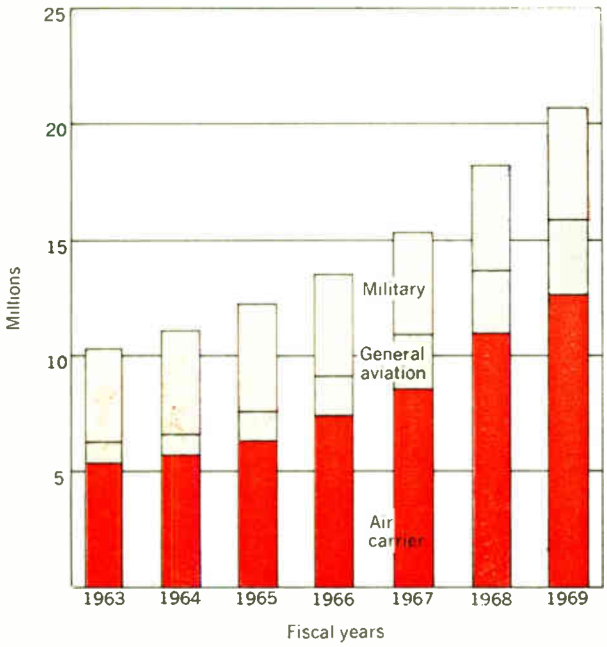


FIGURE 1. Bar graph showing approximate total numbers of aircraft handled under IFR (instrument flight rules) at FAA ARTCCs, by user category.

The ever-increasing volume of aircraft operations of all types (commercial, private, and military) is taxing present terminal and en route control systems and equipment—and air-traffic controllers—to the outer limits of their respective handling capacities and endurance. Thus the Federal Aviation Administration (FAA) has been obliged to formulate detailed plans to meet the challenge of phenomenal aviation growth forecast for the decade of the '70s, and beyond.

For the initial ten-year time slot, the FAA has proposed many system improvements that could be provided by annual appropriations of $250 million for facilities and equipment, and $60 million for R&D. For example, en route and air-terminal automation expanded radar service and coverage, increased federal assistance to airports, and improved navigation and landing aids are some elements now in the planning stage to ensure greater airborne safety, to increase traffic-handling capabilities, and to promote more efficient service for the air passenger. This first installment deals with the ground-control systems that will eventually form an integrated and automated network in the 48 contiguous states of the U.S.

Almost any air traveler who booked a flight from Kennedy International Airport in New York during 1969, particularly in the peak travel months of July and August, may have bitter memories of long-delayed departures caused by the simultaneous queuing of a dozen or more jetliners waiting for takeoff clearance. This situation, in itself, indicated the critical problem of one phase of total airport operations.

The public press, of course, devoted much copy to this airport jam-up; many passengers studiously avoided JFK whenever possible, and the air-traffic controllers captured numerous headlines in giving vent to their tensions, frustrations, and anxieties. Their spokesmen alleged that there were serious inadequacies in existing control systems and in the hardware required to handle the operations in the overcrowded skyways and air terminals. The situation was dramatically—and tragically—emphasized in August 1969, when an Allegheny Airlines DC-9, bound for St. Louis, collided with a small private plane and both aircraft subsequently crashed near Indianapolis. Eighty-three lives were lost in this mid-air collision, the fourth since 1960 in which a commercial airliner was involved. And, on January 17, 1970, four passengers were killed when two single-engine private planes collided in the air near Brainard Field on the outskirts of Hartford, Conn.

From 1964 through 1968, 133 mid-air collisions were recorded, 73 of which caused 193 fatalities.[1] In the majority of these incidents, *general aviation aircraft** were involved. We will never know the total number of near misses that have occurred in recent years (since many of these incidents went unrecorded) in which last-second evasive action took closing aircraft out of potential collision courses.

The available statistics for 1968 indicate a 46 percent increase over 1967 in the number of mid-air accidents.[1] And the 1968 study of the National Transportation Safety Board presented the ominous specter of even grimmer future statistics unless preventive measures and remedial solutions are soon put in effect.

IFR aircraft operations: a decade of rapid escalation

In the 1959–1969 decade, the number of *aircraft operations* of all categories handled at FAA *air route traffic-control centers* (ARTCC), under *instrument flight rules* (IFR), doubled during that period, reaching a peak of 20.6 million in 1969.[2] This figure represented a 14 percent increase over the 18.1 million reported for the previous year. *Air-carrier operations* in 1969 accounted for 12.6 million of the total number of aircraft handled, an increase of 17 percent over 1968. General aviation's share was 3.2 million, also a 17 percent gain over the previous year. Military aircraft totaled more than 4.7 million operations, and represented an increase of 4 percent over 1968. *IFR departures and overs* showed increases in the same slot of 13 and 16 percent, respectively. Figure 1 gives a general indication that reflects the steadily increasing volume of total aircraft handled between 1963 and 1969 at FAA ARTC centers, by user category.

The breakdown by regions, for the years 1968 and 1969 are shown in Table I. From the table, it can be seen that three regions—Eastern, Central, and Southern—handled 66 percent of the 1969 IFR operational workload.

Of the 23 ARTCCs in continental North America (Table II), there were ten centers that handled more than one million aircraft in 1969. The four leaders—Chicago, Cleveland, New York, and Washington—are the cities cited in the same order during 1968.

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* Many of the terms, acronyms, and abbreviations used by the FAA may be unfamiliar to the reader. Thus a glossary is provided at the end of this installment for the reader's assistance. The term, when initially used in this article, will be italicized to indicate its inclusion in the glossary.

I. IFR aircraft handled, departures, and overs at FAA ARTCCs by region: fiscal years 1968 and 1969

	1969		1968		
Region	Number, hundreds of thousands	Percent of Total	Number, hundreds of thousands	Percent of Total	Annual Change, percent
		Aircraft Handled			
Total	*20 562	100	*18 093	100	+14
Eastern	5 280	26	4 776	26	+11
Southern	3 882	19	3 306	18	+17
Central	4 328	21	3 850	21	+12
Southwest	2 773	13	2 388	13	+16
Western	3 482	17	2 988	17	+17
Alaskan	301	1	267	2	+13
Pacific	514	3	520	3	−1
		Departures			
Total	*7 937	100	* 7 035	100	+13
Eastern	*2 057	26	1 887	27	+9
Southern	1 401	18	1 216	17	+15
Central	1 674	21	1 508	21	+11
Southwest	1 160	15	1 018	15	+14
Western	1 364	17	1 159	17	+18
Alaskan	113	1	88	1	+28
Pacific	167	2	159	2	+5
		Overs			
Total	4 688	100	4 025	100	+16
Eastern	1 166	25	1 002	25	+16
Southern	1 080	23	874	22	+24
Central	980	21	834	21	+18
Southwest	543	10	352	9	+29
Western	754	16	670	16	+13
Alaskan	75	1	81	2	−18
Pacific	180	4	202	5	−11

* Detail may not add to totals because of rounding of figures.

. . .But the total volume of operations is overwhelming

Now, hold on to your hat, because if the jet- and propwash from 20.6 million annual operations under IFR seems like a staggering quantity, consider that aircraft operations at individual FAA *airport traffic-control towers*, in which IFR* and VFR (visual flight rules) movements are combined attained a grand total—nationwide—of more than 55.9 million in all user categories in 1969. Recent studies and forecasts indicate the need for 900 additional airports in the U.S. during the 1969–1979 decade. From the Fig. 2 graph, one can see that air-terminal traffic will increase almost 300 percent in the same period. Thus the immense scope of the air-traffic control problem can be appreciated without subjecting the reader to tedium by a continued recital of details.

Transition to automated systems

The steady annual growth of aviation operations dictates the urgent need for greatly improved air-traffic control capabilities in terms of handling capacity, the maintenance of safety criterions, and optimum efficiency in the utilization of available airspace. A giant step forward in FAA planning was the introduction of automatic data-processing techniques at both ARTCC and *approach-control facilities* that provide direct machine aid to the air-traffic controller.[3]

Today, by means of radar monitoring, pilots' reports, and filed flight plans, the controller can follow those aircraft operating on IFR in his area of responsibility. He can maintain the safe-distance separation of aircraft by voice radio instructions to the pilots. And as a flight proceeds through the various discrete sectors of the airspace, control jurisdiction is transferred from one controller to another.

The FAA hopes that, by 1972, en route automation capability will be incorporated at the 21 ARTCCs in the 48 contiguous states of the U.S. The implementation of the program will be in two steps: first, automated flight data-processing capability will be provided; and, by 1974, under Stage A of the National Aviation System Plan, additional computer data-acquisition and on-line communications potential—plus computer-generated displays—will be available.

Thus, for example, the flight characteristics (speed, course, altitude, etc.) of an aircraft en route from Los Angeles to New York would be under continuous on-line automatic surveillance and monitoring from coast to

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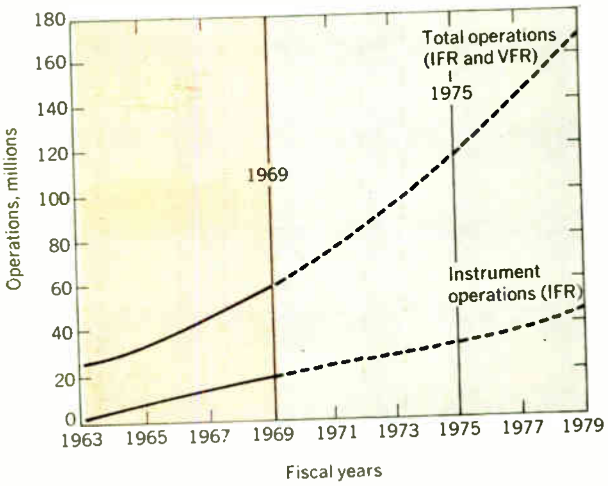
* It should be explained at this point that flight operations under IFR do not necessarily mean that weather, or other operational conditions, preclude visual control and identification of aircraft movements. What it *does* mean is that such aircraft will adhere *at all times* to the instrument flight rules with respect to minimum aircraft separation, speed, and other standard aircraft procedures when in terminal areas and approach patterns.

II. Rank order of FAA ARTCCs by IFR aircraft handled and by IFR departures and overs: Fiscal year 1969

Center	Aircraft Handled		Departures		Overs	
	Rank Order	Number, hundreds of thousands	Rank Order	Number, hundreds of thousands	Rank Order	Number, hundreds of thousands
Total		20 562		7 936		4 688
Chicago, Ill.	1	1 648	1	706	6	234
Cleveland, Ohio	2	1 561	3	547	1	466
New York, N.Y.	3	1 536	2	673	11	190
Washington, D.C.	4	1 177	7	447	4	283
Fort Worth, Tex.	5	1 103	5	466	14	170
Atlanta, Ga.	6	1 094	8	438	9	218
Indianapolis, Ind.	7	1 057	11	353	2	350
Houston, Tex.	8	1 042	6	465	19	110
Los Angeles, Calif.	9	1 028	4	472	21	84
Boston, Mass.	10	1 004	9	389	8	226
Oakland, Calif.	11	954	10	384	12	185
Jacksonville, Fla.	12	890	14	279	3	331
Kansas City, Mo.	13	889	13	338	10	212
Miami, Fla.	14	869	12	349	16	169
Memphis, Tenn.	15	707	16	239	7	228
Albuquerque, N.Mex.	16	626	17	227	13	171
Denver, Colo.	17	591	19	162	5	266
Seattle, Wash.	18	558	15	255	25	47
Minneapolis, Minn.	19	555	18	216	18	123
Honolulu, Hawaii	20	407	20	140	17	126
Salt Lake City, Utah	21	349	22	89	15	170
San Juan, P.R.	22	268	23	81	20	105
Anchorage, Alaska	23	248	21	89	22	68
Great Falls, Mont.	24	177	24	59	23	59
Guam, M. I.	25	106	25	26	24	53
Fairbanks, Alaska	26	52	26	23	27	6
Balboa, C.Z.	27	52	27	13	26	26

FIGURE 2. FAA graph of historical data showing increase in aircraft operations from 1963 to 1969. It includes forecasts of a sharp increase in total operations during the 1969–1979 decade.



coast. Based on data received from satellite computers at the en route ARTCCs, the air-traffic controllers at the aircraft's terminal destination area will have an advance taped program of its estimated time of arrival (ETA), and sufficient identity and other flight data to permit a smoother and more efficient handling of the flight operation during the approach and landing procedures.

The airspace surveillance required by an ARTCC is provided generally at present by radar and beacon sensor systems that furnish aircraft position (azimuth and slant range) data from the antenna orientation and the time delay between the transmitted and reflected radar pulses. While the radar transceiver visually records reflected energy, the beacon equipment triggers and receives signals from a transponder aboard the aircraft (provided it is so equipped). The transponder reply signals can be encoded to convey both the identity of the aircraft and its altitude. These sensor data, however, must be presented to the controller in such form that he can readily accept and understand them.

But the conventional radar plan-position indicator (PPI), which has been in use for many years, has some significant disadvantages in use—with or without transponder and beacon assistance. Among these are

1. The controller must determine which blips on the radarscope correspond to aircraft of concern to him.

2. Once these blips are correlated, he must then hold the discrete identification of each aircraft, even in congested traffic patterns or "clutter" areas in which many video returns are in immediate proximity.

3. With the radar PPI, the controller has but a two-dimensional display; altitude, the critical third dimension of the *air-traffic control* (ATC) *facility* picture, is missing.

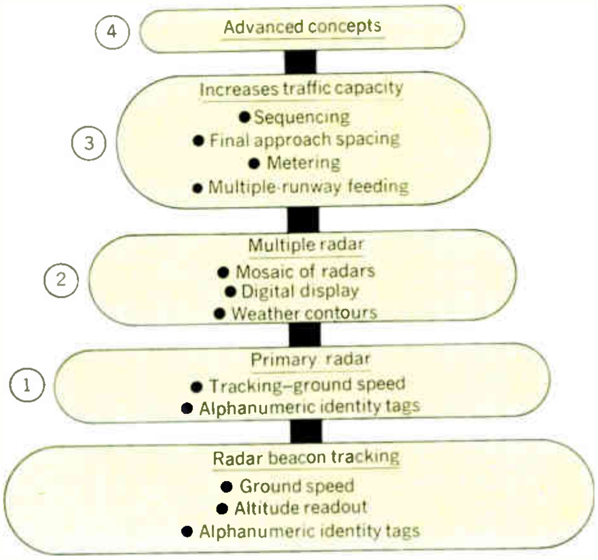


FIGURE 3. Basic ARTS functions, with the proposed add-on functions to achieve ARTS III capabilities. Level 4 is reserved for future components as developed.

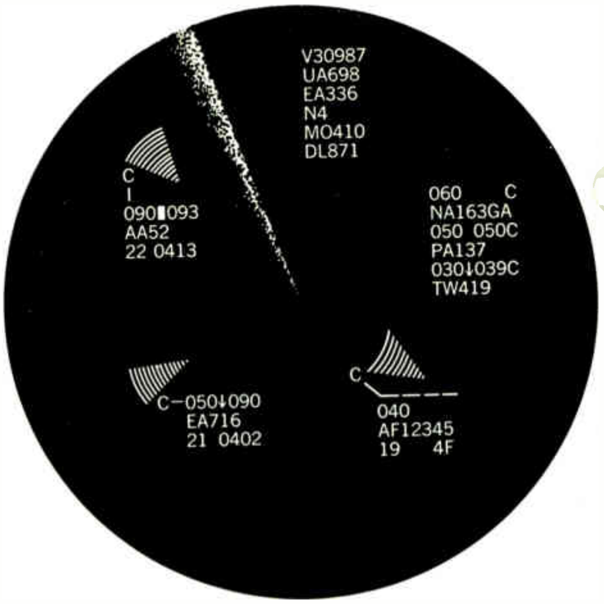


FIGURE 4. Computer-generated and -controlled alphanumeric flight data, in the form of "tags," are superimposed on each video scan sweep on the controller's radarscope. The three tags shown are automatically following the radar and beacon video returns from the targets. Data tables in first quadrant display pending flights and aircraft in holding patterns. The location of these tables on the screen can be shifted at will by the controller. The concentric 10-mile- (16-km-) radius circles, normally shown on the display, have been omitted for clarity in this illustration.

In its attempt to compensate for these deficiencies in complete surveillance information, the FAA several years ago, established a program for the automation of ATC facilities. The primary objective was to provide a fundamental computational base[4] to which supplementary modules could be incorporated to improve safety and increase handling capacity. The initial design of the modular air-terminal system was therefore predicated upon identified functions that could be added to the basic radar equipment (Fig. 3) and modified to suit individual terminal requirements. This led to . . .

ARTS and Atlanta. Armed with a backlog of experimental laboratory data, the FAA next initiated a field trial of terminal automation at its facility in Atlanta, Ga. At this installation, the agency subsequently developed a computer-assisted video system that provides an on-line dynamic display of flight data, in alphanumeric form, directly on the radarscope (Fig. 4).

The basic ARTS (Automated Radar Terminal System) technique affords the controller both aircraft identity and altitude information, from transducer-equipped aircraft transponders, that is continuously coordinated with the proper radar video returns. Significant data from the Atlanta prototype—including modified tracking logic, faster methods of machine address, and alternative displays of control data—are still being evaluated as the facility's personnel debug and smooth the system for optimum performance. These "add-on" functions to the ARTS system's basic capabilities, as indicated in the Fig. 3 block diagram, form the nucleus of the more sophisticated ARTS II and ARTS III programs (which will be discussed later in this article).

Based on the encouraging experience with the Atlanta ARTS, and to meet the urgent need for air-traffic control assistance, the FAA decided in late 1965, to proceed with a second installation in what is now called the . . .

Common IFR Room at the New York terminal area

The New York terminal area is one of the busiest in the world in air-traffic operations[3]; it consists of three major airports (Kennedy International, LaGuardia, and Newark), plus 16 secondary airports such as Teterboro, Wayne, Bethpage, Farmingdale, Floyd Bennett, etc., each of which handles IFR operations. Until July 1968, the control of terminal operations was divided among three separate control facilities (IFR rooms) located at Kennedy, LaGuardia, and Newark. These separate installations were combined into one centralized facility, called the Common IFR Room, which is now in the North Terminal Building at Kennedy International. This consolidated center permits improved flight coordination and more efficient surveillance and utilization of the terminal airspace. It was ideally anticipated that the Common IFR Room (CIFRR) would minimize delays in arrivals and departures by providing more flexibility in flight monitoring and routing through unified control on a fully integrated basis.

With the CIFRR, it was no longer necessary to waste valuable airspace by inserting "buffer zones" between the operations that were formerly controlled at the separate facilities. And since controllers assigned to the various airports now worked side by side, it was reasonable to expect that the coordination of their efforts would be simplified. Also, ATC personnel controlling aircraft in close juxtaposition (but under discrete jurisdiction) share the same radar consoles, including the large-scale screen display projections shown in the introductory illustration (p. 26), which afford a common quick-reference source for all control teams.

Both the controllers' radar consoles and the large-scale wall displays have supplementary alphanumeric

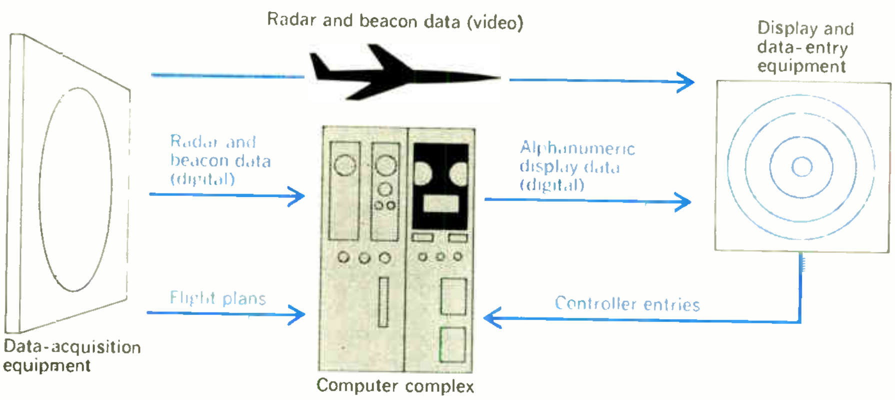


FIGURE 5. Block diagram showing the two primary information paths to the display equipment in the CIFRR: a direct video (radio and beacon) path that provides analog data in the normal manner; and a digital path, via the computer, for the generation of alphanumeric data.

capability. When used in conjunction with ground-based computer control and transponder-equipped aircraft, vital flight information such as aircraft identity, altitude, ground speed, heading, and airport destination is electronically superimposed (Fig. 4) as alphanumeric data block "tags" adjacent to the appropriate radar target blips. These tags automatically follow the aircraft on the visual display as the plane proceeds through the terminal area.

Alphanumeric advantages. In comparison with the conventional PPI display, the significant advantages in having plane identity and altitude continuously present on the radar screen are threefold:

1. The controller no longer needs to make a time-consuming effort just to identify the radar blips of aircraft under his surveillance.

2. He can obtain the necessary altitude information without relying only on pilots' reports (with the attendant hazards of garbled voice communications and possible human error in transmitting data).

3. Since the degree of the controller's attention and amount of communications required in conventional monitoring increases in direct proportion to the number of radar targets, the alphanumeric system permits him to focus his attention more efficiently on the control of a larger number of aircraft.

A parallel benefit for the CIFRR is the manner in which the tag technique facilitates aircraft "handoffs"* from one controller to another. When such responsibility is transferred, the releasing controller pushes a sequence of buttons, which causes the tag for the particular aircraft to appear on the accepting controller's display console. The second controller then pushes a sequence of buttons to indicate that he has accepted the control of that plane. Thus positive transfer of both control and alphanumeric data is achieved by the computer with little or no verbal exchange of aircraft target data.

System hardware and arrangement

Figure 5 is an overall schematic diagram of the hardware, and the primary communications channels, of the CIFRR.[3] It includes data-acquisition and data-display equipments, and a computer complex.

Data-acquisition equipment. The complex job of surveillance and monitoring of the New York terminal area airspace is accomplished by radar and beacon sensors (Fig. 6) situated at Kennedy and Newark Airports. As indicated in the flow diagram, each site is equipped with an airport surveillance radar and a beacon interrogator that provide a 97-km (60-mile) scanning radius in a full-circle sweep. (Actually, three radar systems are utilized by CIFRR controllers: two short-range airport surveillance radars, designated Kennedy ASR-4 and Newark ASR-4, which operate in the range of 2700–2900 MHz, plus the Kennedy long-range air-route surveillance L-band radar, ARSR-2, operating at 1300 MHz, which can monitor a circle-sweep radius of about 130 km, or 80 miles.)

To ensure a fail-safe capability, built-in system redundancy provides a two-channel radar backup. As an additional factor of safety, flight progress strips, containing aircraft identity and altitude data, and the estimated time of a flight over a particular *airway* fix, are automatically printed out on line in the computer complex. These strips are relayed to the controllers as a simultaneous check on the primary visual control, and they can serve as a fail-soft backup in the unlikely event of complete radar failure.

Wide-band communications channels are used for the radar and beacon video signals, and for signal triggering, from the two sensor sites to the CIFRR. The Kennedy radar uses a private land line, but a microwave link is employed for the remote Newark site.

The beacon system (transmitting at 1090 MHz, and receiving at 1030 MHz) accumulates data from transponder-equipped aircraft that can automatically report their identity and altitude. Although many commercial planes carry this equipment, only about 20 percent of these are fitted with the latest type of beacon transponder (capable of transmitting any of 4096 discrete identity codes, thereby permitting the pilot of the aircraft to select a unique identity code for his ship). Most transponders, however, have a 64-code limitation and thus the same identity tag is often assigned to more than one aircraft.

Altitude data are encoded directly from a pressure-sensing on-board transducer, which measures this value in increments of 30.5 meters (100 feet) with respect to a standard atmospheric pressure of 76 cm (29.92 in) of mercury.

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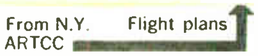
* The CIFRR is equipped with 70 air/ground communications frequencies that are utilized by the facility's various sectors. As an aircraft traverses from one control sector to another, the pilot is advised to switch to the appropriate frequency. This process, when used in conjunction with radar surveillance of the plane's position, is called a "radar handoff," and it keeps the aircraft in uninterrupted radar and radio contact with the appropriate controller.



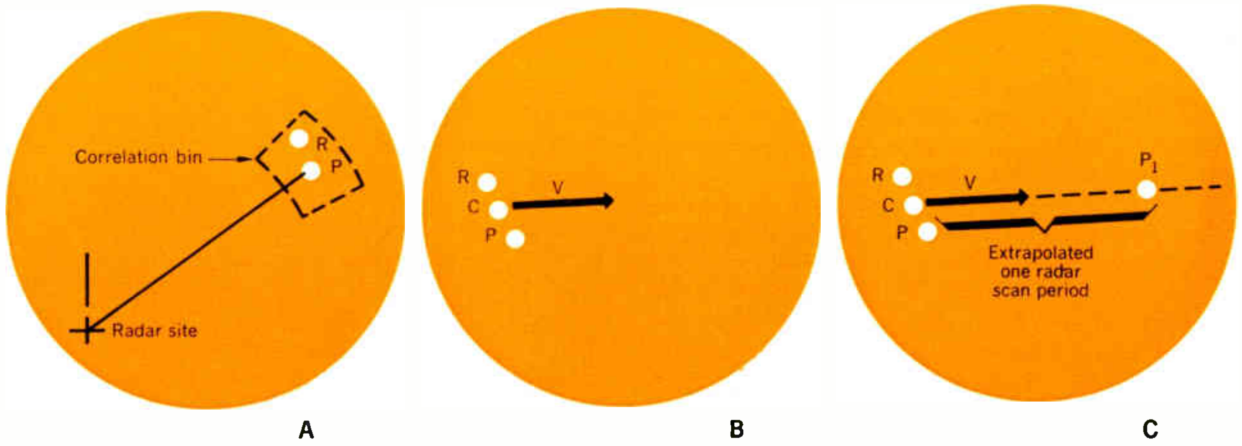


FIGURE 9. A—Step 1 in tracking. For correlation, the track is associated with the new sensor target report either by beacon-identity matching or by position report. In the illustration, the target report "R" is found by positional correlation within "bin," whose center is "P" (the predicted track position). B—For target correction, the present position "C" is calculated, together with velocity vector "V," by using corrective data that are dynamically related to the track-data reliability. C—In track prediction, flight path is extrapolated along velocity vector to "P_1," a subsequent scan sweep. P_1 becomes new position of bin when the track is reprocessed on the next scan of the target.

either keyboard or cursor entry devices. These messages typically contain the controller's instructions and supplementary alphanumeric data pertaining to the flight. If an entry affects the tracking function, it is relayed by the display processor to the tracking processor.

Tracking procedures . . .

Aircraft under the surveillance of the CIFRR are automatically monitored by the tracking processor so that the alphanumeric tags follow the sensor video on the controllers' consoles (transponder-transmitted return blips appear as large triangular "blooms," as shown in Fig. 4, on the radarscope). By the continuous scan-sweep correlation of radar and beacon target reports, the tracking processor computes a dynamic position and velocity for each plane in real time. And flight data, by tag, are associated with the correct aircraft.

Controllers handling Kennedy and LaGuardia air traffic utilize only the radar and beacon reports from the Kennedy sensor. Similarly, Newark Airport controllers rely on the same reports from their own sensor site. These discrete data channels prevent possible radar interference that could be produced by incorrect antenna alignments, signal propagation anomalies, or slant-range corrections.

Target tracking is achieved by relating updated radar and beacon reports with previously received track data, by fixing the present position and speed of the plane, and by predicting where the radar blip will be located on the next scan sweep. Three basic sequences—correlation, correction, and prediction—are performed for every aircraft track once each radar scan sweep (see Fig. 9). If a track fails to correlate during the current scan, however, no corrected data are calculated, and the track is extrapolated [Fig. 9(C)] on the basis of the previous position and speed information. This process is called "coasting" the track. Tracks are automatically terminated by the computer when they are transferred to the destination airport's control tower. Following every prediction sequence, the position of each track is checked to determine whether it fulfills the geographic airspace criterions for automatic termination.

. . . And display data

Flight data are presented to the controller in one of several formats (Fig. 10) depending on whether the aircraft is being actively tracked in the surveillance airspace or is displayed in a tabular store pending an imminent arrival or departure. Each tag, tabular item, or individual symbol to be displayed requires a digital message from the computer specifying the location, format, and content of the display data.

In an active track [Fig. 11(A)], the accompanying alphanumeric tag is positioned according to coordinates predicted by the tracking processor. A line "leader" connects the tag to a single alpha symbol ("K," in this instance,) which denotes the assigned controller at the CIFRR who will be responsible for that aircraft's surveillance while in the airspace. In addition, a velocity vector arrow, with its length proportional to the calculated track speed, may be displayed at the controller's discretion. The tag can contain up to 21 alphanumeric characters arranged in three or four rows—the first, second, and third rows having provision for a maximum of seven characters. As may be seen in the tags and callouts illustrated in Fig. 10, the top line displays the aircraft's identification. If it is a commercial carrier, the identity tag generally consists of the airline's initials plus the flight number. In the next row, the ground speed in knots (18 = 180 knots, in the Figs. 10 and 11 examples) and the reported beacon (Mode "C") altitude are shown. In the illustrations, "063" indicates an altitude of 6300 feet (1920 meters).

The third row of alphanumerics (Fig. 10) contains the assigned altitude in hundreds of feet (050), and the beacon code. The bottom row displays the aircraft's track number (1A) and its destination airport.

Note that the difference, in Fig. 10, between the aircraft's assigned altitude and that reported by the airborne beacon is 1300 feet, or 384 meters. Whenever this differential is 200 feet (61 meters), or more, a flashing square symbol on the console warns the controller of the discrepancy. But the altitude reported by the beacon transponder must be corrected by the display processor before it is visually displayed.*

The bottom row of the Fig. 10 alphanumerics is reserved for the display of alternating supplementary information. Since this line is time-shared to permit the entry of four data items (including tracker-derived aircraft speed, track number, destination airport, and "scratch pad" data inserted by the controller), they are displayed alternately at 8 to 16 seconds' duration for each.

Note in Fig. 11(A) that there is a space directly above the alphanumeric tag for two (of three possible) horizontal bar displays. The continuous-line upper bar is used to mark a track that requires special attention; it is automatically flashed when a monitored aircraft is transmitting an emergency beacon code signal. The dashed-line lower bar indicates a handoff between controller jurisdictions. A broken-line lower bar denotes that the track is being coasted on the basis of extrapolated speed data in the absence of updated scan information. As indicated in Fig. 4, the alphanumeric tag and leader line can be offset in different directions from the track symbol to minimize the overlapping of tags in congested areas of the visual display.

Figure 11(B) shows a typical tabular store listing of imminent flights, which contains only the aircraft's identification, and is alphabetically queued according to the ETA or ETD of the inbound or departing flights.

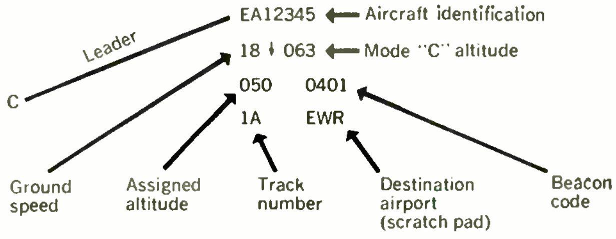
Another tabular display listing [Fig. 11(C)] is reserved for flights assigned to a "holding" pattern during peak terminal operations periods or bad weather condition. The tag data format, in this case, is identical to the first two rows of the active track [Fig. 11(A)], except that an additional alpha symbol is used to indicate the holding fix. Holding items are listed by their chronological order of entry. The controller can readily switch the location of hold and store listings to any convenient portion of the display screen.

Summary of the New York ATC system . . . and . . . How well is it functioning?

Now that we have analyzed, in some detail, the functions of the various component elements of hardware and software that comprise the CIFRR, we can assemble all of the modules and describe and assess the total system performance in the New York terminal area. And it should be emphasized that the CIFRR is unique: there is no similar installation anywhere else at the present time. Common IFR Rooms are being considered, however, for the Chicago terminal area, Oakland–San Francisco, and Dallas–Fort Worth.

Essentially, the CIFRR is responsible for maintaining a safe distance interval between all aircraft flying under IFR procedures, and for providing radar vectors within the New York terminal area airspace (approximately 4200 mi², or 11 000 km²) under its jurisdiction. In addition, service is provided to those aircraft that are operating in visual flight (VFR) conditions within the framework of the National Terminal Radar Service program as well.

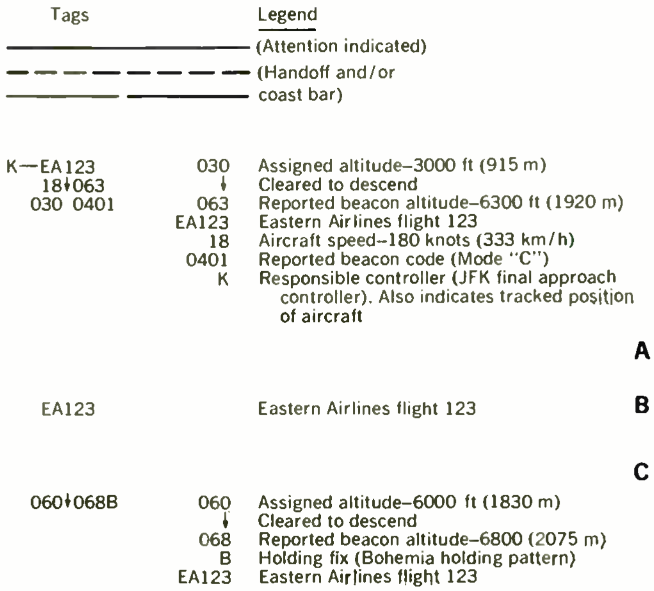
When flying under IFR, a pilot files a flight plan with the ARTCC nearest to his point of departure. This is one of the centers concerned with the en route control of aircraft between terminal areas. When the destination airport is one of those in the New York terminal area, the New York Center (being the nearest ARTCC) hands off the aircraft, at a predetermined point, to the CIFRR, which then assumes control responsibility



Note: "EWR" is the standard code designation for Newark Airport

FIGURE 10. One format of an alphanumeric display. Each tag, tabular item, or individual symbol displayed requires a digital message from the computer to specify the location, format, and content of the display data.

FIGURE 11. A—In an active track, the alphanumeric display format contains up to 21 characters. The tag is attached to the track position symbol "K" by a leader. Indicator bars, as shown, can be displayed above the tag to denote a special flight status (emergency situation, handoff, or coast). B—Items in the "tabular store list" consist only of the identity of a pending flight, and the list is queued according to the time of flight arrival or departure. C—Each entry in the "tabular hold list" refers to an aircraft assigned to a holding pattern. This listing is queued by chronological order of entry.



Notes: JFK is code for Kennedy International.

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* For aircraft flying below 18 000 feet (5500 meters), compensation must be made for the difference between local barometric pressure and the standard reference pressure (76.0 cm, or 29.92 inches, Hg) used by the altitude sensor on board the transponder-equipped aircraft. This error-correction routine is part of the ground-based computer program.

for the flight until the subject plane is about 5 miles (9 km) from its destination. At this point, the local airport control tower takes over to effect the touchdown that concludes the flight.

At the present time, there are about 900 air-traffic controllers in the New York terminal area, of which about 170 are assigned to the CIFRR. The three major airports, plus Teterboro, are among the most heavily trafficked airfields in the U.S. In fiscal year 1969, there were, for example, 1.54 million aircraft handled in the terminal area. And with a steady annual increase of 9 to 13 percent in aircraft operations, the situation of the air-traffic controllers has passed within the margin of tolerable safety—for a number of reasons.

First of all, what we have been discussing in the preceding description of computer-controlled automation in the CIFRR dealt ideally with radar and beacon ground sensors operated in conjunction with transponder-equipped (secondary radar) aircraft that are compatible with the generation of alphanumeric tag displays and target-tracking procedures. But unfortunately, only about 20 percent of the total number of aircraft handled carry the type of on-board electronic equipment capable of transmitting positive readout of all necessary flight data. In most airspace surveillance, the controllers detect targets by "skin paint" video returns (ordinary blips produced by the signal echo) on the primary radar. Certain adverse weather conditions (including temperature inversions) can distort or preclude the primary radar signal. Since vectoring, to be effective, must start at 40 to 50 miles (65–80 km) from the airport, one can appreciate the initial problems that may be caused by radar signal degradation. The data acquisition can be further complicated by the necessary reliance on voice radio communications between the controller and the pilot, with the attendant possibilities of human error in instrument readout, and misinterpreted information and instructions in transmission or reception.

The heterogeneous mix of the types of aircraft handled in the airspace—from helicopter "sky taxis," and relatively slow single-engine private planes, to subsonic jet airliners and military aircraft—creates many variable and unpredictable factors in aircraft maneuverability and reaction time required to comply with ground instructions. Further, many of the aircraft tracked are "IFR overs" (see Table I)—flights that originate outside the ARTC area and pass through the terminal airspace without landing. These transients must also be handled by the controllers.

The writer visited the CIFRR on a cold weekday morning last January, half expecting to witness a scene of crackling tension and crisis comparable to that of the War Room at NORAD after the "red alert" was sounded in *Dr. Strangelove*. But instead, the atmosphere was one of quiet order in which all of the controllers' actions were executed with an impressive degree of calm efficiency. In short, the mood at the time of the visit was in striking contrast to that pictured in *The New York Times Magazine*'s article of September 30, 1969, on the air-traffic controllers of the CIFRR (i.e., consoles awash with half-empty paper coffee cups, mounds of cigaret butts in ash trays, and bleary-eyed, open-collared controllers responding to a myriad of emergency situations).

Probably, neither the appearance of tranquillity nor that of frenetic urgency is truly representative of the average datum condition in the room. Bad situations can literally arise "out of the blue" quickly enough to give the most seasoned controller a bad case of the jumping jitters. And a midweek morning call in midwinter is not usually a time to observe peak-traffic operations. There are two seasonal traffic peaks: summer (July–August), and winter (December–January). The primary peak is the summer one, when both overseas and domestic commercial flights are in greatest demand by vacationers. During the secondary winter peak, flights to Florida, the Caribbean, and South America cause a noticeable increase in operational activities. Historically, the high point during the week has been on Friday and Sunday evenings.

Another factor in the overall picture is that of air cargo flights, which have increased very significantly in recent years, especially since the advent of the giant turboprop and pure jet commerical and military cargo planes. Although the percentage of such flights at Kennedy International is small, a larger number of these operations are handled at both LaGuardia and Newark Airports. Further, air cargo arrivals and departures are less predictable than those of scheduled commercial airliners. Thus a peak time in cargo operations could be after midnight on any weekday, or during a heavy traffic period on a summer weekend.

Plans are under consideration for the decentralization of the air cargo carriers to satellite airports such as the former Republic Aviation field at Farmingdale, L.I. (now operated by the Metropolitan Transportation Authority), Suffolk County Airport, and Stewart Air Force Base near Newburgh, N.Y. The last-mentioned field has been deactivated by the USAF and, being adjacent to the New York State Thruway, it would make a good site for an air freight depot.

An air-traffic controller speaks out. James H. Loos, a controller in the CIFRR, is an articulate spokesman for many of his colleagues in the New York terminal area. He is no stranger to the public press, since he was the subject of a feature profile last year in *The New York Times Magazine* article mentioned earlier in this piece. Mr. Loos, unlike most of his fellow controllers, is a college graduate, and is a skilled air-traffic controller whose initial training and experience was acquired while serving in the USAF. As is the case with all air-traffic controller candidates, he was put through an intensive special training period before being assigned to the CIFRR.

Writing about some of the controllers' gripes and problems in the January 1970 issue of *The Journal of Air Traffic Control*,[5] Loos says, in part:

"A little over a year ago I was involved with drawing up and presenting a list of recommendations on how to improve the air traffic service in the New York area. The people involved in the task with me were prepared to offer responsible arguments supporting any proposal that received a 'no' answer from the FAA. The amazing thing is that we received few if any 'no' answers. What happened was that our proposals slowly sunk in the quagmire of official FAA channels, never to be seen again. . . This is especially frustrating to a controller, since his daily environment is one of extreme immediacy. When a situation develops, a controller must take steps right away, reactions must come quickly. When his hierarchy does not react in the same way it is most frustrating; he becomes alienated from his own particular society.

"The result was a manufactured crisis. Controllers stopped working hard [during the summer of 1969], traffic backed up, the communications media discovered us, and we suddenly became famous.

"The question is, did it solve anything? Not much, and for every problem it resolved it probably created another one.

"We are no closer to another jetport in New York today than we were a year ago. Restrictions on [private] flying have been discussed and implemented, but our mission is to facilitate the movement of people, not hamper it. More [air-traffic-control] personnel were authorized, but much of the money was used to provide overtime pay and many positions were left vacant . . .

"The authority of the management of the FAA has been questioned and the leadership has been far from dynamic. To be fair to them, they are probably caught in the same quagmire of bureaucratic channels and conflicting, powerful interests that hamper much of our governmental apparatus."

The FAA reply—and plans

The writer interviewed a number of FAA officials in both New York and Washington. They admitted that the ATC personnel indeed constitute an understaffed group. Normally, the controllers in the CIFRR work on three eight-hour shifts around the clock. And, often, during peak operation periods, considerable overtime work is required. The agency hopes initially to augment the staff of 900 controllers in the New York terminal area by about 250 men, and to make the necessary proportional increases at other major airports throughout the U.S. where understaffing is a problem. And hope is still expressed for a fourth jetport that will be constructed far enough away from the New York terminal system to be independently controlled.

Further, the FAA contends that 70 to 80 percent of the controllers' proposals for system improvements have been implemented, and there is disagreement with Jim Loos concerning the reasons for the controllers' brief "slowdown" in 1969.

Parenthetically, it may be well to interpolate one moot question at this point: What will be the effect on a large terminal area of the 747 "jumbo" jets that are being placed in service in increasing numbers for both overseas and domestic flights? As of now, not enough experience has been gained in actually handling these outsized aircraft to evoke much more than cautious comment. The FAA administrators and the controllers seem to agree that the big birds will just be another blip on the radar screen and another piece of traffic handled. They feel that the 747s will pose more of a ground problem (in loading and unloading time and space required) than an airborne one. It is conceded, however, that their takeoff time is longer and their rate of climb is slower. Right now, Kennedy International is the only New York airport capable of handling these planes.

The FAA is presently implementing some plans to ease the traffic congestion in terminal areas. One of these schemes involves the "Metroplex" system, which will provide for more equal flight separations along new departure routes (see Fig. 12) and will also change

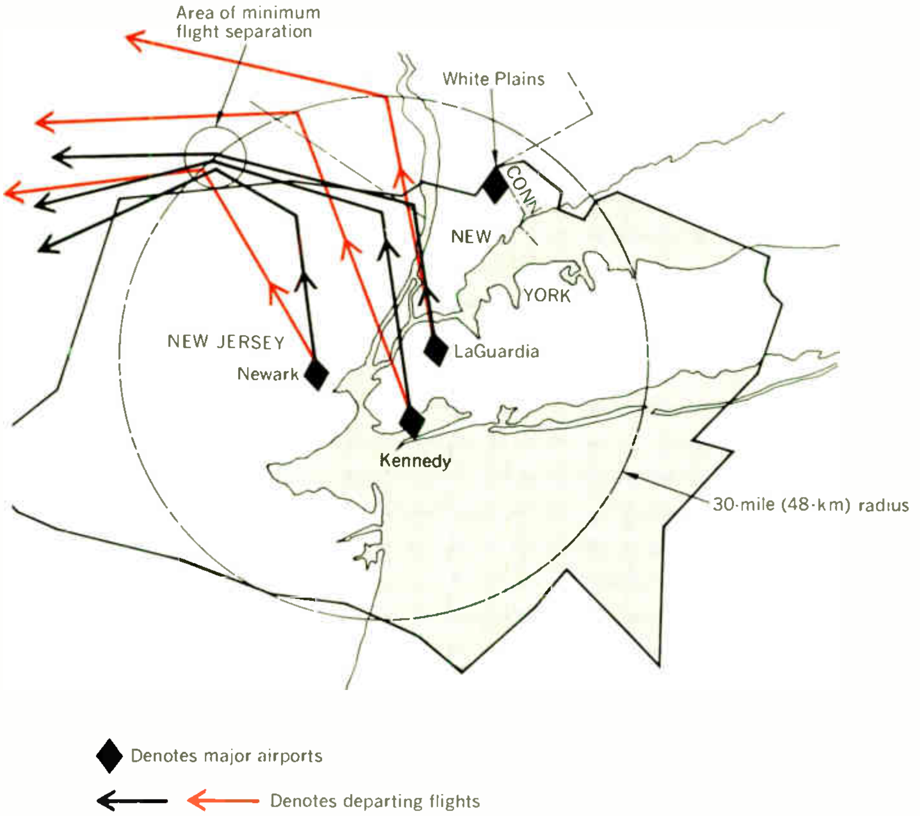


FIGURE 12. Under present departure patterns (in black), flights taking off from the three major airports in the New York terminal area, and bound for southern or western destinations, tend to veer to their departure courses in an area of possible minimum flight separations. Under the "Metroplex" plan (in color), more equidistant flight separations, along new departure routes, will be provided. Also, the arrival "fixes" will be changed by inserting a new "arrival hold" program.

the arrival fixes by inserting a new "arrival hold" program. Westchester County Airport (White Plains) is participating in the Metroplex plan; radar handoffs are in effect between White Plains and other airports in the New York terminal region.

In another interim action, the FAA, under a quota system, is moving general aviation (non-air carrier) traffic out of the three major New York airports to the satellite fields, notably to Teterboro, where significant runway improvements are being made.

Terminal automation (ARTS III). A contract for 64 units of the more sophisticated Advanced Radar Terminal System (ARTS III), which incorporates the add-on functions of the basic ARTS system (refer to the Fig. 3 block diagram), was awarded to equipment manufacturers by the FAA early in 1969. These systems are initially planned for 62 large- and medium-sized hub terminal facilities. And second-stage plans call for an additional 52 ARTS III systems, for a total of 114 operational installations in all. Two extra systems will be used for training and R&D purposes. A scaled-down version of automated terminal radar (ARTS II)* is scheduled for installation and operation at secondary terminals before the end of fiscal year 1974.

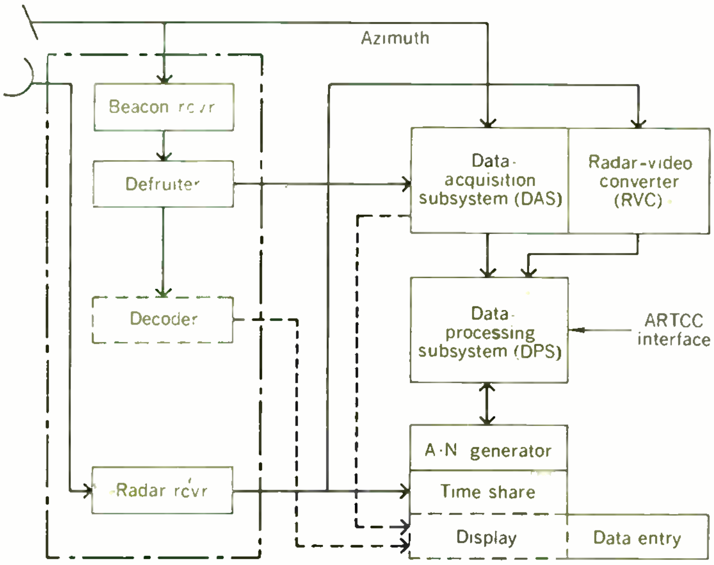
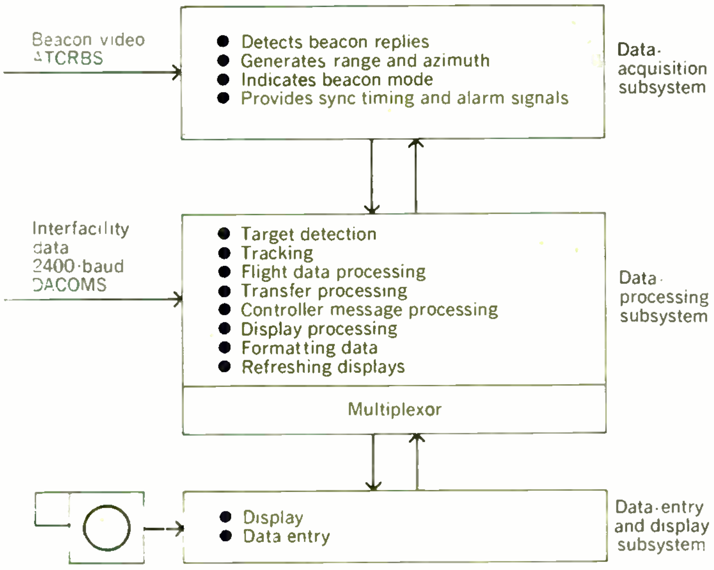


FIGURE 13. Block diagram of the basic ARTS III system. Note that a data-acquisition subsystem (DAS) is added to the radar video converter.

FIGURE 14. Block diagram indicating the allocation of ARTS III system tasks within the capabilities of the three principal computer subsystems.



In addition to the basic ARTS functions shown in the Fig. 3 block diagram, ARTS III[4] features include on-line transfer of data from satellite ARTCC computers to terminal computers, and automatic track data acquisition on discrete-coded beacon-equipped aircraft. Nondiscrete-coded signals from aircraft can be acquired manually by the controller by what is called a "track slue" and entry. By means of intrafacility handoffs, controllers can spot-check data from another display console within the control room.

Referring back to Fig. 3, the first level (1) added to the basic ARTS concept, to achieve ARTS III capabilities, is the radar tracking level. Digitizing the primary radar data permits an alphanumeric tag to be assigned to aircraft that are not equipped with transponders. This action is not automatic, however, and requires data entries by the controllers. If these targets, for example, are low-speed private aircraft that may remain in the terminal control airspace for periods of 10 to 15 minutes, the extra tracking effort can pay off as an added safety factor.

The next hierarchy (2) is the transition to the digital level, which permits the combination of several radar inputs into a mosaic display. Level 3 allows the introduction of automated telemetering, sequencing, and final-approach spacing techniques.

Figure 13 is a block diagram of the fundamental ARTS III system. Note that a data-acquisition subsystem (DAS) is added to the radar video converter (from the present primary and secondary radars). Figure 14 indicates the allocation of ARTS III system tasks within the three main computer subsystems.

Figure 15 is a diagram representing the ARTS III, level 3 capabilities. It shows time-sequence plots of a flight through a terminal area (in this case, Atlanta Airport) in which machine assistance provides the capability of "close-order" traffic control for minimum aircraft spacing and maximum handling capacity. The alphanumeric code used for FASA (final approach spacing of aircraft) targets is explained in this figure.

Tower automation. The FAA also has plans to automate the present highly manual functions in airport control towers. Figure 16 is a flow diagram showing how data, in tabular form, will come directly to a tabular display at the ground-control position. From here, with a single-button action, the data can be quickly transferred to other positions. Off-line data can be relayed to the control center for either historical records, legal

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* ARTS II refers to a type of system presently being considered for the balance of the existing radar facilities, and for some new radar facilities. At the present time, there are two candidate systems: a programmable alphanumeric ARTS II system with ARTS III components, and the FAA–Department of Defense numeric Direct Altitude and Identity System (DAIR). For additional information on the latter configuration, the reader is referred to the May 1969 issue of *The Journal of Air Traffic Control.*

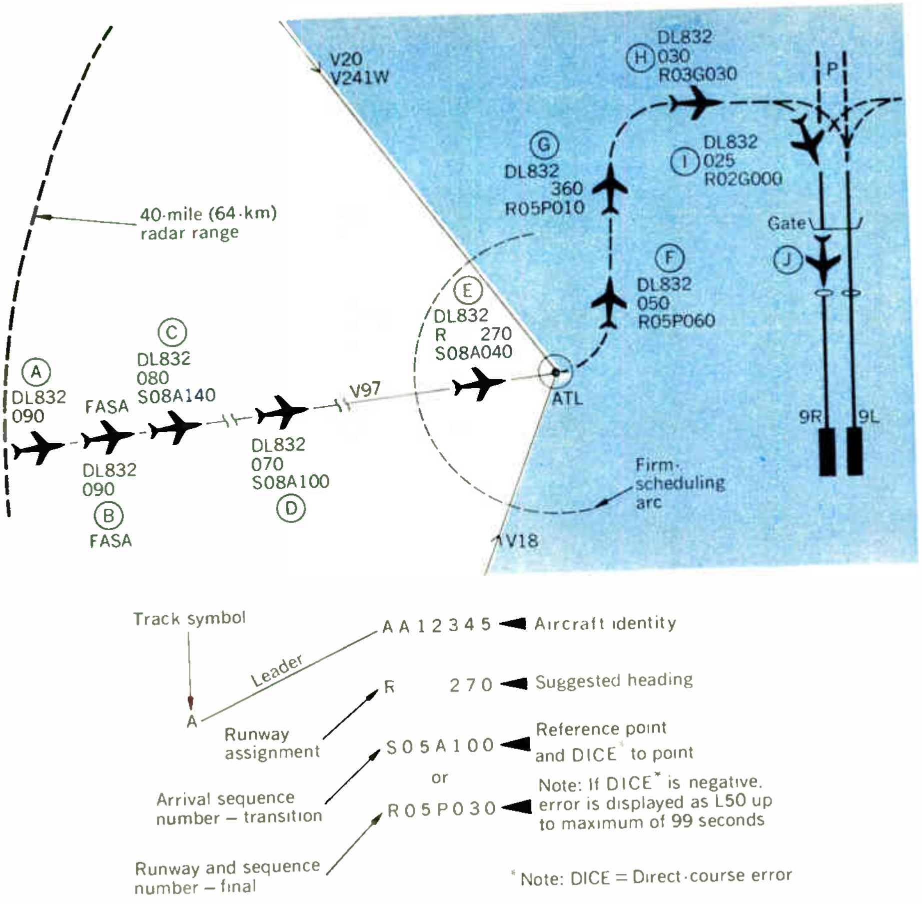

FIGURE 15. Diagram of ARTS III, level 3 capabilities. Time-sequence plots of a flight through the Atlanta terminal area are shown. Machine assistance provides the capability of "close-order" traffic control for minimum aircraft spacing and maximum handling capacity. The alphanumeric code, used for FASA (final approach spacing of aircraft) targets, is explained below the sketch.

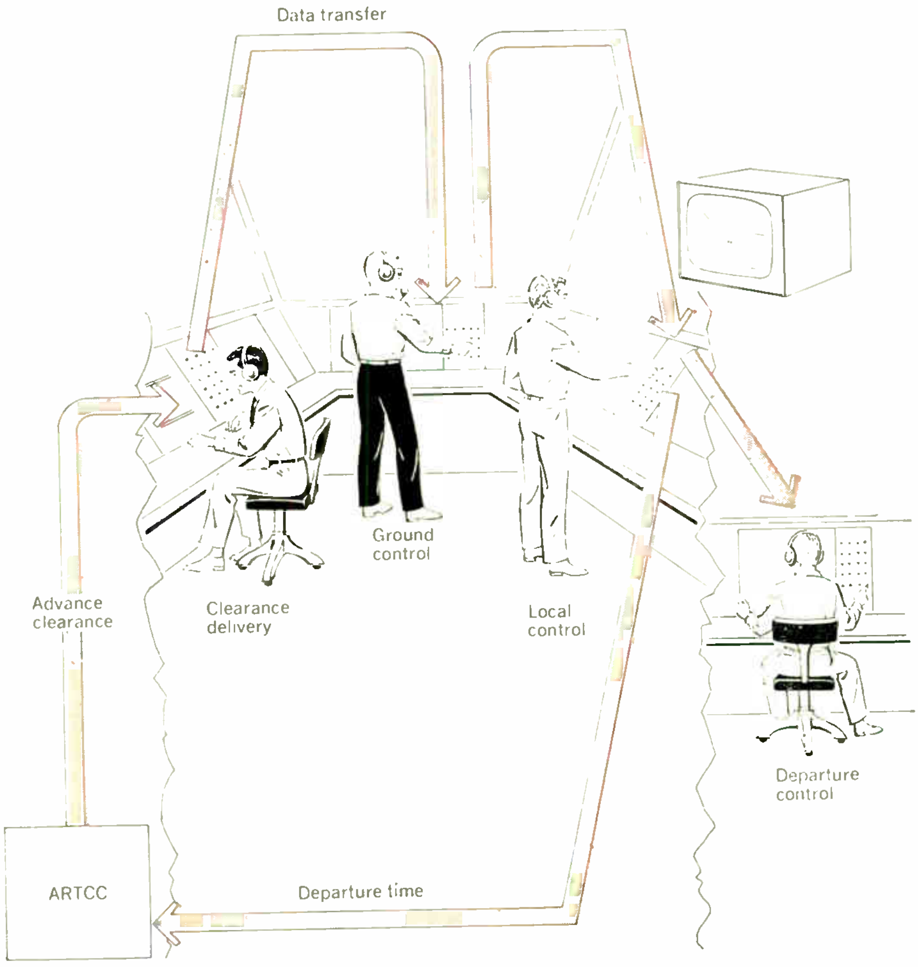

FIGURE 16. Flow diagram indicating how data, in tabular form, will come directly to a tabular display at the various ground-control positions when control tower functions are integrated into a common control system.

evidence, or subsequent analysis for program debugging or updating. In view of the trend toward integrated common control facilities, the automation of tower functions is becoming more urgent in the general scheme. The tower can provide a key interface with many of the airport ground-control systems presently under development by the FAA.

Preview of installment two

In the next issue we shall continue the discussion of the FAA's plans for the future by presenting in detail several schemes either now being implemented or in the R&D stages. These include plans for automated ground control, en route automation, collision-avoidance systems, improved communications and long-distance navigational aids, etc.

By way of postscript

On March 25, the Professional Air Traffic Controllers Organization (PATCO) initiated a job action, or "sick-out," at ARTCCs and air terminal centers throughout the U.S. This situation, in which 25 to 50 percent of the ATC personnel called in sick, was particularly effective in crippling air-carrier operations in the New York terminal area. Most flights during the Easter weekend were delayed up to four hours in departure, and many other scheduled flights were cancelled. A court order directing the leadership of PATCO to direct the controllers to report back to work failed to achieve that objective. According to PATCO spokesmen, the controllers were following the regulations of IFR procedures to the letter in observing aircraft separation and other safety procedures. But it was apparent that the controllers were emphasizing their grievances in what they alleged to be insufficient personnel and machines available for executing their jobs without excessive nervous tension, overtime, and safety hazards.

Despite court orders and injunctions issued to restrain PATCO, the sick-out lasted for 20 days. On April 13, the job action officially ended when all of the absented controllers returned.

Appendix. Glossary

Air-carrier operations. Aircraft operating under certificates of public convenience and necessity, issued by the Civil Aviation Board (CAB), authorizing the performance of scheduled air transportation over specified routes and a limited amount of nonscheduled operations.

Aircraft operation. An aircraft arrival at or departure from an airport with FAA airport traffic-control service. There are two types of operations: local and itinerant. Local operations are performed by aircraft that

1. Operate in the local traffic pattern or within sight of the airport tower.
2. Are known to be departing for, or arriving from, flight in local practice areas located within a 20-mile (32-km) radius of the control tower.
3. Execute simulated instrument approaches or low passes at the airport.

Itinerant operations include all aircraft arrivals and departures other than local operations.

Airport traffic-control tower. A central operations facility in the terminal air-traffic control system, consisting of a tower cab structure, including an associated IFR room if radar equipped, and using air/ground communications and/or radar, visual signaling and other devices, to provide safe and expeditious movement of terminal air traffic.

Air route traffic-control center (ARTCC). A central operations facility in the air route traffic-control systems using air/ground communications and/or radar, and primarily providing en route separation and safe, expeditious movement of aircraft operating under instrument flight rules within the airspace of that center.

Air-traffic control (ATC) facility. A facility in the U.S., its possessions and territories, and in foreign countries, especially established by international agreement, that has the capability of providing air-traffic control services to the flying public.

Airway. A portion of the navigable airspace of the U.S. designated by the FAA as a federal airway.

Approach-control facility. A terminal-area traffic-control facility that provides service to arriving and/or departing IFR flights and, on occasion, VFR flights.

General aviation aircraft. All civil aircraft except those classified as air carriers.

IFR departures. These include IFR flights that

1. Originate in an ARTCC's area.
2. Are extended by an ARTCC.
3. Are accepted by an ARTCC under *sole en route* clearance procedures.

IFR overs. An IFR flight that originates outside the air route traffic-control area and passes through the area without landing.

Instrument flight rules (IFR). FAA rules that govern the procedures for conducting instrument flight.

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Gordon D. Friedlander (SM), staff writer for IEEE Spectrum, has written more than 30 major features for the core publication since he originally joined the staff in 1963. In 1968, he accepted the position of assistant director of the Burndy History of Science Library, Norwalk, Conn. He rejoined Spectrum early this year.

Mr. Friedlander is a graduate civil engineer, with 15 years' experience as a structural and project engineer, and was engaged in the design of steam-electric and hydro power plants, and industrial and commercial buildings. Since 1959, his technical articles have been published in leading newspapers, encyclopedias, and trade and professional magazines in both the U.S. and abroad. In 1967, he served as the technology consultant on The New York Times' "Committee of the Future." Mr. Friedlander has lectured on engineering management at The University of Wisconsin's Engineering Institute seminars, at IEEE Group Meetings, and for the Industrial Education Institute. He moderated a radio panel discussion program series called "Science and Technology" for two years on Station WEVD, New York. His biographical sketch is carried in "Who's Who in the East."

A modernized electric network for the future needs of Hamburg

To benefit fully from the distribution system in the Federal Republic of Germany, Hamburg has matched its main distribution lines to the country's 380-kV transmission network

Jens Meinert, Klaus Peter Ewelt

Hamburgische Electricitäts-Werke AG

Among the "city-states" in the Federal Republic of Germany, the plight of Hamburg—with respect to its electrical needs—is, if not typical, then representative of conditions that exist in other cities in the republic. To meet the growing electric needs of the populace, a Hamburg electric utility has devised a system that will take full advantage of existing services incorporated into a new "broader backbone." Plans call for sufficient redundancy to permit operation at all levels with a minimum of downtime. At no time will interruption last more than one hour; most often it will amount to only minutes or seconds. As the need arises, the system will grow and grow—hopefully not outstripping its potential until the turn of the century.

The demand for electricity in the Federal Republic of Germany (F.R.G.), as expected, consistently has increased over the years. By far the greatest increase in electric demand is attributable to greater household consumption.

Overall, the use of electricity in Germany increased 9 percent in 1968, yet the comparable augmentation for home use was 13 percent. In fact, household demand for electricity now accounts for nearly one fourth of the total; ten years ago it accounted for only about 15 percent (see Fig. 1). This trend doubtlessly will continue as the increasing affluence of the home dweller whets his desire for additional conveniences and comforts. At present, the homeowner is switching to electricity to supply his heating needs (see Fig. 2, relevant to increased winter load). Later, he should be in a position to buy air-conditioning.

Many cities, consequently, are outgrowing their electric-power distribution service. Often, lines are overloaded—a condition that is conducive to failure. However, services are being updated.

Hamburg may not be a typical German city. It has, however, many of the same electrical-supply problems that afflict other German cities. What is planned for Hamburg by way of modernization, therefore, will provide some insight into the primary features of a remodeled electric network for a city in the F.R.G.

Hamburg is a federal state with 1.8 million inhabitants and the largest "town" of the F.R.G., covering an area of about 750 km² (290 mi²). Roughly half of it is urbanized; the remaining portion consists of agricultural, forest, or park area. The region supplied with electricity by the Hamburgische Electricitäts-Werke (HEW) is identical with the area of the State of Hamburg.

For the last five years or so, HEW has been faced with the fact that the present supply arrangement, established in the late forties, is approaching its limit.

This arrangement consists of four voltage levels (110 kV, 25 kV, 10 or 6 kV, and 0.38 kV). Limitations on transmission capacity and fault level will not allow the 110-kV system to be tied into the large power stations that are planned or under construction. Moreover, the intermediate 25-kV level is becoming more and more uneconomical.

These circumstances have led to a revision of supply at all voltage levels and to the development of a new scheme with a 380-kV system at its upper level. The new concept permits the continued effective usage of the present facilities.

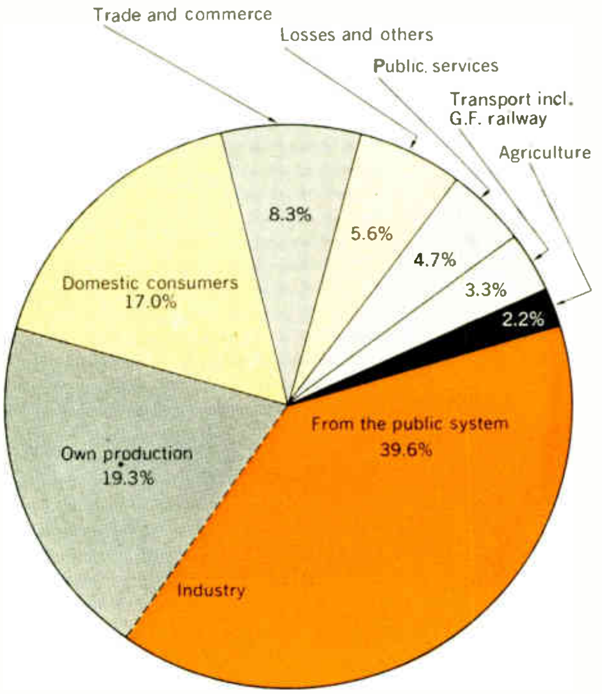

FIGURE 1. This is how the consumption of electricity was apportioned in 1968. Since then, in the F.R.G., the domestic-consumer share has grown to nearly 25 percent.

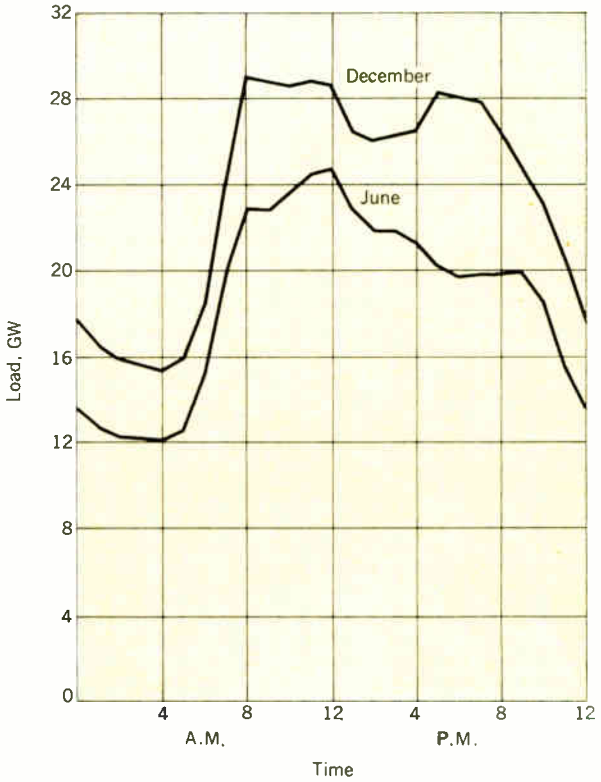

FIGURE 2. Part of the difference between winter and summer electric consumption in the households of the F.R.G. is created, of course, by the need for longer periods of artificial light. However, a growing share of the difference is attributable to an expanding use of electric heat.

Design criterions

The future supply system will have four voltage levels (380 kV, 110 kV, 10 kV, and 0.38 kV) and will have to meet the requirements of long-term design, design simplicity, and design reliability.

Long-term design. The systems are to be extendable to about eight times present maximum demand, in steps. (Because unforeseeable technical developments may change presently established concepts, it is not sound to plan to exceed this growth figure.)

Simplicity of design. The new system will have only a few voltage levels and standardized equipment. It thus will be easy to enlarge without sacrificing the simplicity of its modular design.

There will be one standard-size 380/110-kV transformer and two standard sizes of 110/10-kV transformers. Only the 10/0.38-kV transformers will be available in five sizes—to better match the different load structures in the 0.38-kV systems.

Buried cables, overhead lines, switchgear, and apparatus are also to be limited to a few standard sizes.

Reliability of supply. The method of supply will permit outage of an entire power station without any system component being permanently overloaded during a switchover period to backup or alternate facilities (from within the system or from a neighboring utility). Basically, the reserve capacity of the system provides for a single contingency only—because of the expenses that would accumulate with such redundancy.

In the 380-kV system no service interruption is allowed when there is an outage of any one component. In the 110-kV system, a single fault causes either no service interruption at all, or restoration of an interruption within a few seconds by automatic switchover to the spare component. Single faults in those 10-kV systems in which subordinate 0.38-kV systems are operated as meshed networks will normally cause no service interruptions. Where the 0.38-kV system is not meshed, a 10-kV fault will cause a service interruption of up to one hour.[1]

Coincident outage of two parallel circuits (second contingency) may lead to longer service interruptions. These interruptions, however, will be limited to a specific area because of the radial supply arrangement. Avalanching, causing the outage of areas that have not been involved initially, is therefore not expected to occur.

Basic supply principle

The basic principle of supply is shown in Fig. 3. A main feature is that all large power stations will feed into the 380-kV system. Power, therefore, will flow mainly from the superposed 380-kV system (the backbone) via the 110-kV system into the 10-kV distribution system. The 110-kV system will be relegated to that of a high-capacity, high-voltage distribution system. The present subordinate 10- or 6-kV distribution system will have been completely converted to 10 kV within the next ten years.

The 380/110-kV stations, called 380/110-kV main-transformer stations, must be located on the fringe of the supply area because of property and right-of-way difficulties. Since only a portion of their power is needed in their vicinity, strong 110-kV overhead lines are necessary to carry the power to a second category of stations,

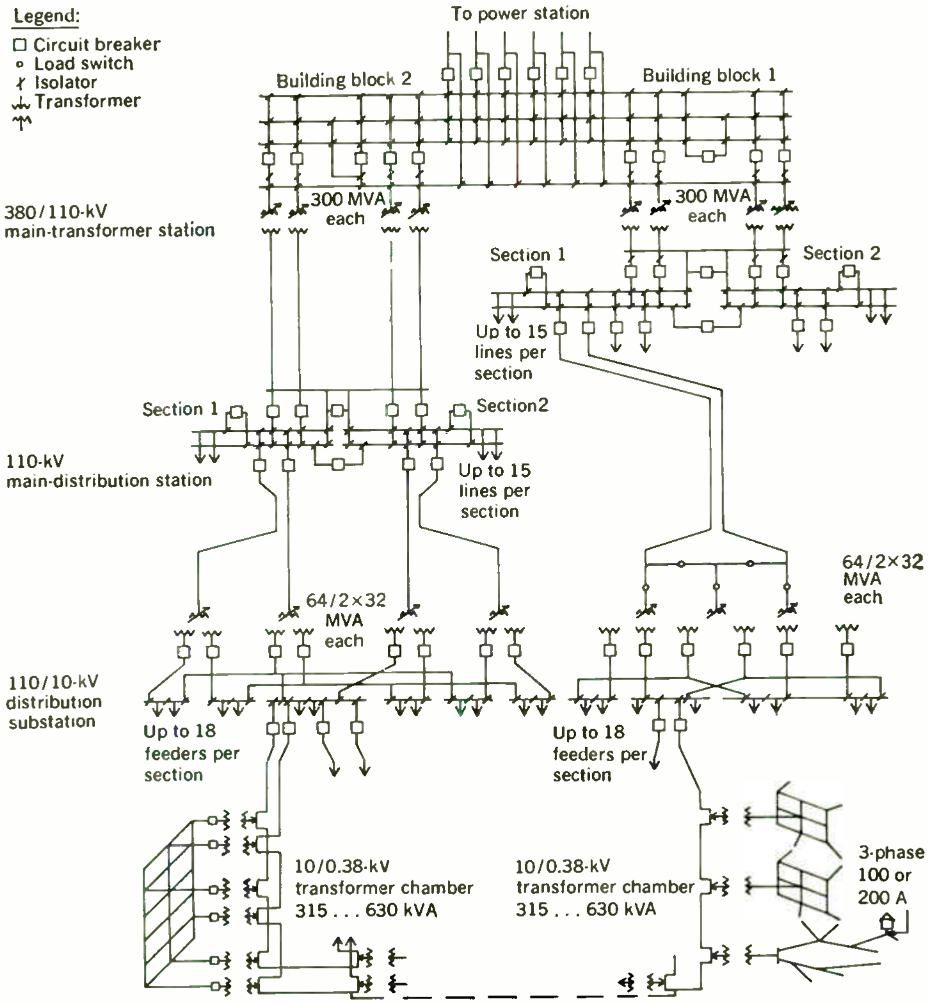

FIGURE 3. One of the main features of the basic principle of electricity supply for the city of Hamburg now being implemented is that all large power stations will feed into the system, thus helping to assure sufficient contingent supplies.

called 110-kV main-distribution stations, which are situated nearer to demand sites. An outline of the 380/110-kV main system as it will exist to meet an eightfold increase over the present maximum demand is shown in Fig. 4.

The 110/10-kV transformers, a third category of stations, called 110/10-kV distribution substations, are connected directly to the 110-kV bus bars of the main-transformer and main-distribution stations, mostly via underground cables, but sometimes via overhead lines.

The 10-kV bus bars of distribution substations feed open 10-kV loops, which connect with 10/0.38-kV transformers. The 0.38-kV systems are operated as meshed networks or as isles.

380-kV lines

The 380-kV system is planned as a semiring, surrounding the eastern half of Hamburg. The supplementary section completing the full ring will be formed by a neighboring utility. The eastern semiring will consist of a double-circuit line, equipped with quadruple-bundle conductors, 4 × 240/40 mm² AlSt (4 × 473/79 MCM ACSR), connecting the three 380/110-kV main-transformer stations.

The 380-kV bus bars in these main-transformer stations will pick up double-circuit lines coming from large power stations. These lines will have sufficient capacity to carry the whole power station output over one of the two circuits in case of emergency. The short length of these lines (less than 100 km) permits use to their ultimate—i.e., to the extent of their thermal-loading—capability.

380-kV plant

Each 380-kV main-transformer station will consist of so-called building blocks with a rated throughput of 1200 MVA per building block. The plant will be equipped with two bus bars for normal service (operating bus bars), one reserve bus bar, and one bypass bus bar.

The two operating bus bars will be permanently coupled. For each pair of circuits—arriving or outgoing—one circuit will be connected to the first bus bar, the other to the second one. Called "operation with coupled double bus bars," this special mode has the advantage of avoiding a service interruption in case of a bus-bar outage (Fig. 5): The reserve bus bar permits this special mode of operation to be sustained during

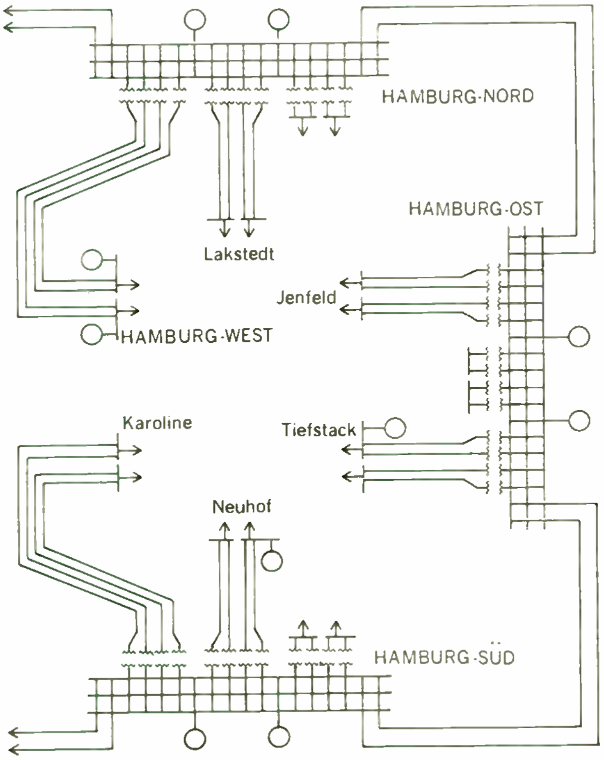

FIGURE 4. The 380/110-kV system is outlined in its ultimate future configuration. At that time it will have eight times its present capacity.

maintenance of an "operating" bus bar; the bypass bus bar permits maintenance of a circuit breaker without need for disconnecting the circuit.

In order to carry out all of the switching operations just described, two bus couplers will be provided: one for permanently coupling the two operating bus bars, the second for functioning as combined couple and bypass breaker to effect switchover in case of faults or need for maintenance.

The rated fault level chosen for the 380-kV switchgear is 40 000 MVA.

380/110-kV transformers

The 380/110-kV transformers will be three-phase with a rated capability of 300 MVA and a cooling system that can be overloaded (up to 400 MVA) for several hours. Because of the differences in neutral grounding of the 380- and 110-kV levels, the 380/110-kV transformer have to be of the two-winding type. They will be star-star connected with a 3-kV tertiary winding rated at 100 MVA. The transformation ratio will be 400 ± 16 percent/120 kV; the on-load tap changers will have 27 steps.

In order to keep the fault level in the 110-kV system within the permissible limit, the 380/110-kV transformer impedance is to be 18 percent of that for the main transformer.

Four transformers form one building block, and each building block normally feeds two 110-kV sections. In the case of a transformer outage, the two 110-kV sections are coupled and each of the remaining three transformers are loaded up to 400 MVA. This means that 1200 MVA per building block is available during an emergency.

110-kV plant. The 110-kV plant of a building block consists of two sections, each having two bus bars. Each feeder is attached to one of the two sections and can be connected to either bus bar. Only the input lines will be provided with a bypass bus bar.

Four bus couplers are needed—two longitudinal and two transversal. The former couples the two sections in case of a transformer outage, the latter permanently couples the two bus bars of a section.

Contrary to methods practiced for the 380-kV plants, in the 110-kV plants the special mode of operation (with coupled double bus bars) cannot eliminate interruptions should a bus bar fail. This condition results because each 110-kV bus bar feeds 110/10-kV transformers via single lines. The number of the 110/10-kV transformers affected by a bus-bar interruption, however, roughly will be half that without use of the double bus.

The rated fault level of the 110-kV switchgear in 380/110-kV main-transformer stations will be 5000 MVA.

Up to 20 operating 110/10-kV transformers, rated at 64 MVA each, as well as five to ten reserve transformers may be connected to the 110-kV plant of each building block. As long as the maximum load of the first building block does not exceed 1200 MVA, the lines running to the 110-kV main-distribution stations have to be connected to the 110-kV bus bars of the 380/110-kV main-transformer stations. With erection of the second building block, these lines may be connected directly to the 380/110-kV transformers.

110-kV main-distribution stations

The 110-kV main-distribution centers are switching stations situated closer to the areas of demand and connected to the 380/110-kV main-transformer stations via overhead lines of high load-carrying capability. A main-distribution station may be regarded as the forward 110-kV member of a main-station building block. It feeds the 110/10-kV distribution substations spread over the supply area, but concentrated in its inner part.

Main-distribution stations have the same setup as 110-kV plants of main-transformer stations, with the exception of a lower-rated fault level (4000 MVA). Seven 110-kV main-distribution stations have been planned.

The connections between main-transformer stations and main-distribution stations normally will be four-circuit lines with double bundles $2 \times 435/55\text{-mm}^2$ AlSt ($2 \times 857/108$-MCM ACSR). (The size of the line is determined by the sag ensuing during an emergency load when temperatures may reach 120°C.)

These operating conditions imply that each circuit is able to transmit 300 MVA normally and 400 MVA in emergency—i.e., it has the same power ratings as a 380/110-kV transformer. Reserve for a circuit outage is provided by coupling to sections of a station, as in the case of a 380/110-kV transformer outage.

110/10-kV distribution substations

A 110/10-kV distribution substation ultimately will have three operating 64-MVA transformers and one reserve transformer of the same size. This means a maximum emergency throughput of $3 \times 64 = 192$ MVA (one transformer outage).

Each 110/10-kV transformer normally will be connected to the main-distribution station via a single

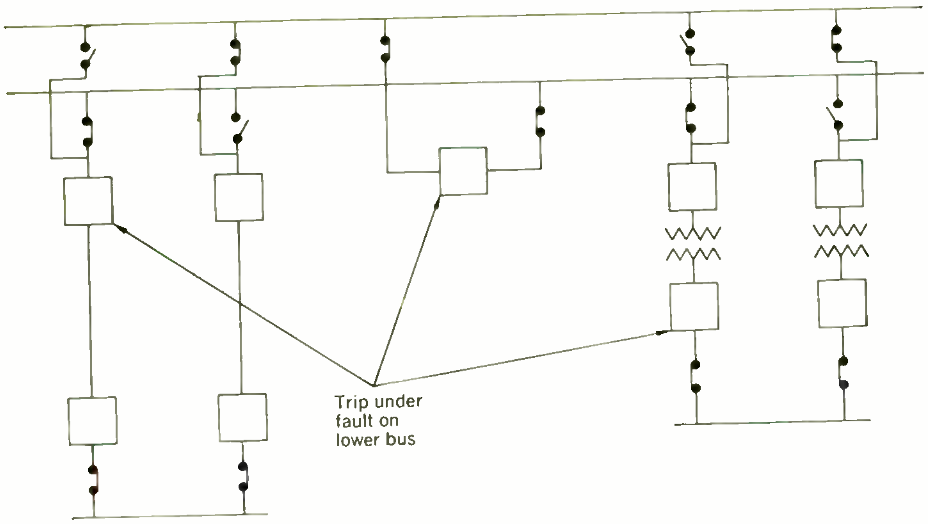

FIGURE 5. Operation with coupled double bus bars.

120-mm^2 copper cable (237 MCM). In the outskirts, distribution substations may be fed by double-circuit, 110-kV overhead lines. The reserve transformer can then be connected to either of the circuits by means of load switches if necessary, since there is ample overhead line ampacity (see Fig. 3).

The operating 110/10-kV transformers of a distribution substation will be connected to different 110-kV bus bars of the main-transformer or main-distribution station. This procedure limits the number of operating transformers that can suffer outage to one per distribution substation, and this can be replaced by the spare unit.

The 110/10-kV transformer winding ratio is 115 ± 16 percent/10.5 kV, adjustable on load in 27 steps. The 10-kV voltage level will be controlled automatically, dependent on load, eliminating voltage control for subordinate systems.

For better load matching, two transformer sizes will be used (32 and 64 MVA). The 64-MVA transformers will have two separate 10-kV windings, 32 MVA each, for feeding two 10-kV sections. The reserve transformer can be connected to each 10-kV section of the substation. The substations will be equipped with insulating, compound-clad 10-kV single bus bars, each separated into two halves. The operating and reserve transformers will be connected to different halves.

With a load of up to 2 MVA per 10-kV feeder, each 32-MVA section will have about 18 outgoing feeders for the load diversity. This implies a total of some 100 outgoing 10-kV feeders per distribution substation fully loaded at nearly 200 MVA. Special measures (such as cooling) may be needed for accommodating all feeders in the adjoining streets.

Investigations have shown that by making full use of the available space, a load of nearly 200 MVA can be transformed within the volume of the present 25/6-kV substations having 40-MVA throughput. The two old 6-kV sections, 20 MVA each, can be changed into four 10-kV sections, 32 MVA each. Two additional 32-MVA sections can be housed in the former 25-kV plant. Only the 110/10-kV transformer chambers have to be extended.

Since each 10-kV section is fed by a single transformer connected to a single 110-kV cable, it suffers an outage when a transformer or cable fails. By automatic switchover to the reserve transformer this outage will last a few seconds only.

The 110/10-kV distribution substations will need no local staff. If 10-kV feeder breakers trip, notification will be transmitted to a central-system control room, and a crew ordered to the respective station via VHF communication to carry out switching and fault-clearing operations.

10-kV system

The 10-kV systems mainly consist of buried cables—standard size of 150-mm^2 Al (296 MCM). Only a few 10-kV overhead lines are still to be found in the outskirts.

As all 10-kV feeders coming from the same 10-kV bus bar serve a distinct area, there are many separate 10-kV sections. A 10-kV loop starts from one side of a 10-kV bus bar and returns to the other side. A loop will serve up to ten 10/0.38-kV transformer chambers connected to it via load switches. Each loop is open in one of the transformer chambers. Ideally, conditions should be such that equal loading of the two semiloops is obtained. A feeder is loaded up to 2 MVA, about half thermal rating.

In the case of a semiloop outage, the faulty section between two transformer chambers is manually isolated, the previous disconnection point closed, and the semiloop portion still out of service is switched in by the 10-kV feeder breaker in the substation. Fault localization and switching operations may last up to 60 minutes.

0.38-kV system

At the 0.38-kV level, there are three modes of operation, depending mainly on load density.

Areas of high load densities (above 5 MVA/km^2, i.e., about 13 MVA/mi^2) are supplied by meshed 0.38-kV networks. Each meshed network is limited to the area fed from one 10-kV bus bar of a distribution substation. This practice prevents coupling of 10-kV bus bars via the 0.38-kV network, thereby avoiding undesired balance currents. Besides this advantage, restoration of a whole meshed network after complete outage can be carried out easily.

In areas of medium load density (1–5 MVA/km^2, i.e., 2.5–13 MVA/mi^2), the 0.38-kV system is meshed only within the service area of a transformer chamber. Each transformer chamber serves a section. The connections to neighboring sections are normally open. In the case of a transformer-chamber outage, its service area will be fed from the neighboring sections after insertion of fringe fuses.

In the outskirts, the 0.38-kV feeders within the service area of a transformer chamber are radial. There are some coupling possibilities between the feeders of adjacent transformer chambers.

In areas above 1 MVA/km^2 (2.5 MVA/mi^2), nearly all 0.38-kV feeders run underground. The cabling of overhead lines also is proceeding in areas of low load densities. All new customers are served with three-phase cables to supply electricity for such high-power appliances as 21-kW instantaneous water heaters.

The standard line for 0.38 kV is 3 × 150-mm^2 (296-MCM) aluminum sheath cable—exclusively used for the last ten years or so.

Any fault in the 0.38-kV cable system will normally burn itself clear. In meshed networks the burnthrough will not be noticed because cables are fed from both sides. Service interruptions in the 0.38-kV-section systems are reported by the affected customers; restoration is carried out by a mobile crew.

Current status

The 380-kV semiring surrounding the eastern half of Hamburg is in operation with 110 kV and will be converted to 380 kV in 1970–71. The second half of the ring, belonging to the neighboring utility, consists of a 220-kV double-circuit line. The tie line to the West German interconnected 380-kV system is to be commissioned in 1970.

Two 380/110-kV main-transformer stations are scheduled to be put into operation in 1970–71, the third in 1974. Each of the three stations initially will be equipped with two transformers, giving an emergency loading of 400 MVA per station.

The first 380/110-kV main-transformer-station, 110-kV plant is in operation; two others are to be commissioned in 1970 and 1973. Six of a total of seven 110-kV main-distribution stations are in operation; the seventh is under construction. At present all 110-kV plants consist of a single section with two bus bars.

The four-circuit lines between main-transformer and main-distribution stations are in operation or under construction except for one line scheduled for operation after 1980. Some of these lines initially will be operated as double-circuit lines with the other two circuits added later.

Several 110/10-kV distribution substations equipped with 32-MVA transformers are already in operation, but there is only one station with 64-MVA transformers in existence.

The old 25-kV system continues its decline as a source for 25/6-kV substations. For the near future it will be utilized for feeding up to 32 MVA to the 110/10-kV distribution-substation reserve transformers. Later (post-1980), the 25-kV system mainly will be used to feed industrial customers having loads of 5–20 MVA.

The 6-kV level, spread over large portions of the supply area, is being uprated to 10 kV. The rated voltage of the equipment is 10 kV and the cables have proved sufficient for 10-kV operation. Before uprating to 10 kV is effected, a dc voltage of 46 kV between phases and between phase and ground is applied to each cable for ten minutes. Uprated portions of the 6-kV system have been proven under operating conditions.

Orders for all new 6/0.38-kV transformers for transformer chambers and customer plants have specified, for the past several years, that transformers be convertible from 6 to 10 kV.

Treatment of system neutrals

The 380-kV system will be solidly grounded; the earth fault current is expected to reach 15 kA in the initial stage and 40 kA once the system is fully developed.

The 110-kV system over heavily built-up areas is resonant grounded via Petersen coils. A changeover to neutral grounding via impedances is under investigation. This would require expensive measures, however, as earth fault-voltage gradients near overhead-line poles and interference voltages on communication lines have to be reduced to a level permitted by conservative German regulations.

The 10-kV system neutrals are isolated, with the exception of large systems where neutrals may be grounded via a Petersen coil.

The planned electricity supply system of Hamburg will provide up to eightfold present demand, a provision that may be expected to serve satisfactorily through to the turn of this century. Such a framework should contribute to a long-term economy and reliability of supply.

This article is based on a paper presented at the IEEE Winter Power Meeting, New York, N.Y., Jan. 25–30, 1970.

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Jens Meinert earned the Dipl. Ing. degree in electrical-power engineering from the Technical University of Stuttgart, Federal Republic of Germany, in 1958 and thereupon joined the Hamburgische Electricitäts-Werke AG as a price evaluator. In 1961, he transferred to the utility's Planning Department and participated in the development of its high-voltage system. In this connection he investigated the contingencies of overloading, reactive-power systems, and the development of new supply schemes among other problems. Mr. Meinert is currently working with a special task force that is responsible for the design and construction of a nuclear plant.

Klaus Peter Ewelt joined the Hamburgische Electrictäts-Werke AG, Hamburg, Federal Republic of Germany, after receiving the Dipl. Ing. degree in electrical engineering from the Technical University of Berlin (West Berlin) in 1957. His duties with the utility have involved design of the low-voltage interconnected network, the uprating of the 6-kV underground cable system to 10 kV, and the development of supply schemes. In addition, he is presently working on the various problems of long-term system planning, reliability, and overload capability. Mr. Ewelt is a member of the Verban Deutscher Elecktrotechniker.

Coding and its application in space communications

Once regarded as purely academic, coding theory has turned out to be eminently practical for the modern applications of space channels

G. David Forney, Jr. **Codex Corporation**

Between 1948—when Shannon first proposed his basic theorems on information theory—and the start of the space age, little practical application developed from the lessons of coding theory. This article presents an overview of the Shannon theorem, interesting practical codes, and their application to the space channel. It turns out that a simple encoder in combination with a decoder of modest complexity placed into an uncoded communications system can increase the data rate by a factor of four or more depending on the coding scheme and the allowable error rate. Use of a convolutional code with sequential decoding has proved to be the outstanding scheme for these applications. It appears that, in the future, coding will find a place in most new digital space communication systems.

Coding theory has a history no doubt unique among engineering disciplines: the ultimate theorems came first, practical applications later. For many years after Shannon's announcement of the basic theorems of information theory in 1948, the absence of any actual realization of the exciting improvements promised by the theory was a source of some embarassment to workers in the field. A standard feature of IEEE Conventions in this period was a session entitled "Progress in Information Theory," or something similar, in which the talks purporting to show that the theory was approaching practical application tended instead to confirm the prejudices of practical men that information theory would do nothing for them.

In retrospect, there were two principal reasons for this lag. First, Shannon's coding theorems were existence theorems, which showed that within a large class of coding schemes there existed some schemes—nearly all, actually—that could give arbitrarily low error rates at any information rate up to a critical rate called channel capacity. The theorems gave no clue to the actual construction of such schemes, however, and the search for coding techniques capable of remotely approaching the theoretical capacity proved so difficult that a folk theorem was proposed: "All codes are good, except those we can think of."

Second, the channels of practical interest—telephone lines, cable, microwave, troposcatter, and HF radio—proved not to have anything like the statistical regularity assumed in the proof of the coding theorems. In fact, most theorems are based on the assumption of statistical independence in the noise affecting each transmitted symbol, whereas on the channels just cited disturbances tend to be manifested in bursts spanning many bits. This is to say nothing of other anomalies that arise in practice, such as a channel described at a recent information theory symposium as "a very good channel, with errors predominantly due to a noisy Coke machine near the receiver."

Over the past decade, the situation has improved tremendously. The problem of finding workable coding schemes has been recognized to be fundamentally a problem of finding decoders of reasonable complexity. The solution has been sought in considering classes of

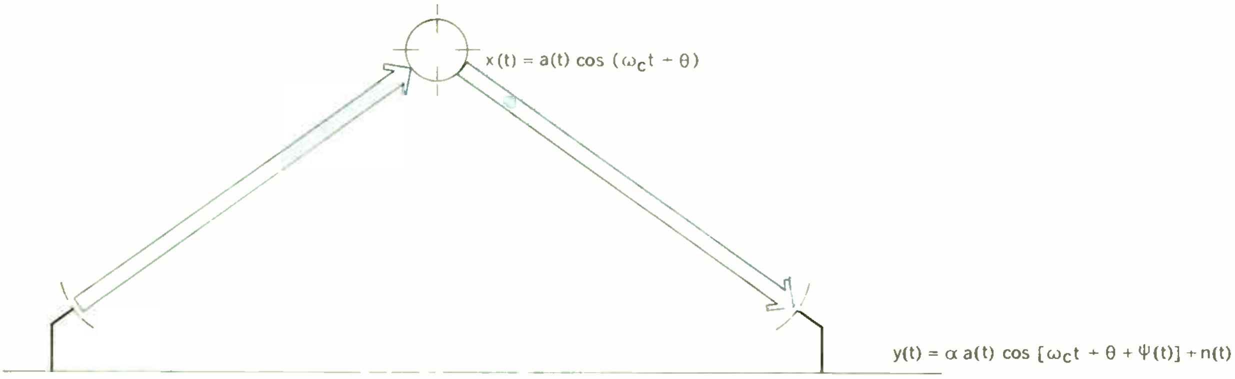
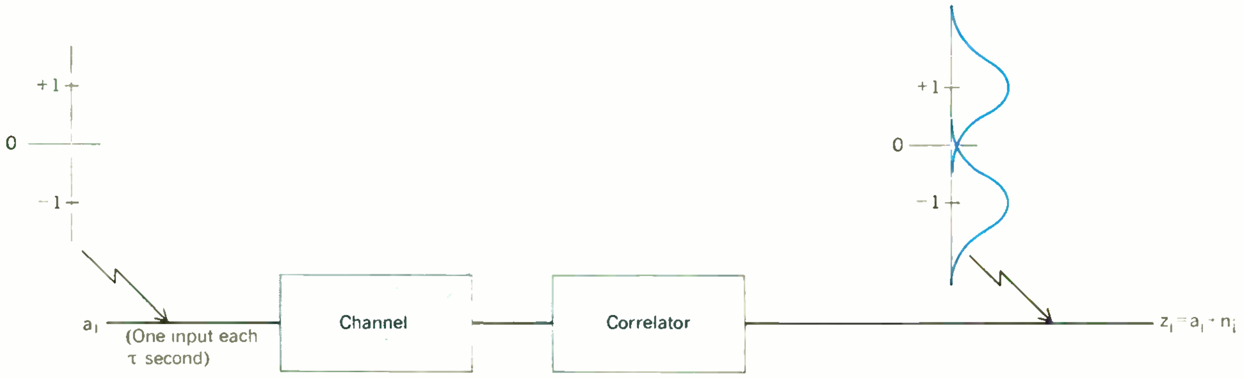


FIGURE 1. Amplitude modulation on a satellite channel.

FIGURE 2. Discrete-time channel model.



codes so structured that efficient decoding becomes feasible (but not so much structured that the codes themselves are no good). The most popular approach has been to use the structures of abstract algebra to generate classes of good, decodable block codes. A second approach uses linear sequential circuits to generate a class of codes that are called convolutional; at least for the applications to be discussed here, convolutional codes seem to have better balance between structure and randomness than is capable with the perhaps too-structured block codes.

A second major development of the last decade has been the emergence of the space channel into practical importance, both in the requirements of NASA for efficient transmission from deep-space probes, and in the proliferation of earth-orbiting communications satellites. The remarkable characteristic of the space channel is that, within the sensitivity of tests performed to date, it appears to be accurately modeled as a white-Gaussian-noise channel. Anyone who has ever taken a statistical subject knows that white Gaussian noise is the archetype of statistically regular, nonbursty noise, and as such is the theorist's dream. Consequently, in considering possible schemes for the space channel, one may use the most profound theorems, the most subtle analyses, and the most accurate simulations. One is also able to propose the most sophisticated and powerful decoding procedures, and predict performance to the accuracy of a fraction of a decibel. The initial successes of coding on the space channel have led to its incorporation in all space-system designs (of which the author is aware) in the last two years or so. For this reason, as well as the pedagogical neatness of the white-Gaussian-noise channel, this article uses the space channel for both orientation and motivation. We shall say little about the literally more mundane channels mentioned earlier, for although applications of coding have also been increasing in those environments, the schemes used are much more *ad hoc*, and more than qualitative predictions about behavior on real channels rarely can be made.

The space channel

The model of the space channel that we shall use reflects all the significant characteristics of the channel, without some details important only in practice; it is illustrated in Fig. 1. An amplitude-modulated carrier

$$x(t) = a(t) \cos(\omega_c t + \theta)$$

is generated aboard a satellite and transmitted to an earth antenna. (Frequency and phase modulation are also used, but not as often as AM, and offer no advantage in principle.) The model still applies when the signal actually originates at another ground station and the satellite is only a repeater, since the power available on the ground is so much greater than that aboard the satellite that the uplink may be considered perfect in most cases. The received signal

$$y(t) = \alpha a(t) \cos[\omega_c t + \theta + \psi(t)] + n(t)$$

is subject to several principal disturbances:

1. Simple attenuation α due to distance (assumed perfectly linear). The received signal power is denoted P.

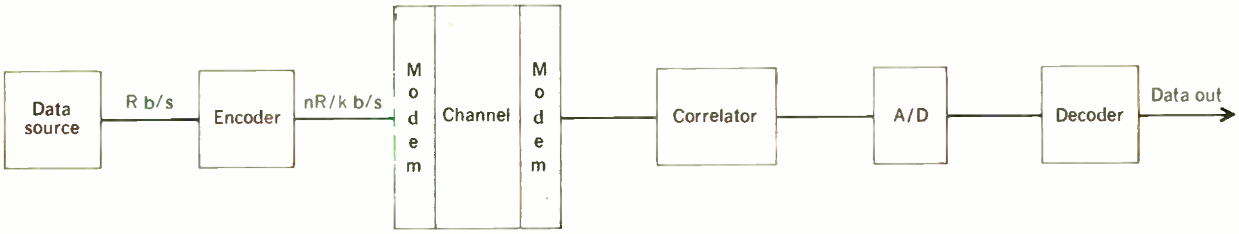


FIGURE 3. System block diagram.

2. Additive white Gaussian noise $n(t)$ arising in the receiver front end, with single-sided spectral density N_o.

3. Phase variations $\psi(t)$ due to imperfect tracking, uncompensated Doppler shifts, an unstable carrier oscillator, and so forth. In the applications with which the author is familiar, with the carrier ω_c in S band, the phase variations are the only important departure from the ideal white-Gaussian-noise model, and make themselves felt at low data rates by frustrating perfectly coherent demodulation. On a NASA mission with a terminal of the Goldstone type, phase variations can be kept to a few hertz or less, and are unimportant unless the bit rate is of the order of 10 bits per second or less. However, in some military applications where the receiver is aboard a plane, ship, jeep, or other moving platform, "low" data rates may be as high as 75 to 2400 b/s. We shall assume hereafter that we are at high enough rates that essentially perfect phase tracking and coherent demodulation can be maintained.

It will also be assumed that the information to be transmitted is already in digital form, leaving totally aside the kind of coding (source coding) that is concerned with efficient representation of the information in bits. (The gains from efficient source coding may be expected to equal or exceed those claimed in the following for efficient channel coding. The best techniques of the infant field of data compression are, however, even more *ad hoc* than those for channel coding on bursty channels.) The information rate will be denoted as R b/s.

When a communications system can pass R information bits per second over a white Gaussian channel on which the received power is P and the noise density N_o, with some acceptable quality, we say that the system is operating at a *signal-to-noise ratio per information bit* $E_b/N_o = P/N_oR$. This dimensionless parameter then serves as a figure of merit for different coding and modulation schemes. Note that it incorporates any effective power loss due to coding redundancy. A system designer who simply wants to select a communications scheme to get the most data rate for a given power and receiver noise temperature, or to use the least power for a fixed data rate, will pick the scheme that can operate at the lowest E_b/N_o with adequate quality (if he can possibly afford it).

An appropriate modulation technique, and the only one we shall consider, is pure time-discrete, N-level amplitude modulation. By this we mean that the modulating waveform $a(t)$ can only change at discrete intervals τ seconds apart, and during any τ-second period, sometimes called a baud, it can take on one of N discrete values, usually equally spaced. We let a_i be the value in the ith interval. If N is a power of two, say 2^m, then the *signaling rate* is $1/\tau$ symbols (bauds) per second, and the *transmitted rate* m/τ bits per second. Ideally, the bandwidth occupied is $W = ½\tau$ hertz, but this is only an approximation (and a lower bound) to the practical bandwidth. By far the most common scheme of this class is the binary ($N = 2$) case, with $a(t) = \pm 1$; this is commonly called PSK or phase-shift keying, the terminology arising from a viewpoint in which $a(t)$ has constant magnitude 1 and the phase θ is modulated to the two values $\pm \pi/2$.

With white Gaussian noise, and perfect phase tracking, it is appropriate to use a correlation or matched filter receiver. Mathematically, in the ith baud such a receiver forms the integral

$$z_i = \int_{i\tau}^{i\tau+\tau} y(t) \cos\,[\omega_c t + \theta + \psi(t)]\,dt$$

It is easily shown that $z_i = a_i + n_i$, where a_i is the modulation amplitude (scaled) in the ith baud and n_i is the noise, a Gaussian random variable centered on 0 and independent from baud to baud. (This assumes perfect synchronization of the timing intervals, which can be approached as closely as desired in practice.) Furthermore, no information is lost in the correlation operation, in the sense that any decision on what was sent that is based on the correlator outputs z_i can be just as good as the information based on the complete received waveform. Thus we have replaced our continuous-time model with a discrete-time model, illustrated in Fig. 2 for PSK. Every τ seconds, a level a_i (one of N) is sent, and a correlator output z_i is received.

In the absence of coding, a *hard decision* is made on the correlator output as to which level was actually sent. For example, with binary PSK, a positive z_i leads to a decision of $+1$, and negative to -1. With coding, it is usually desirable to keep an indication of how reliable the decision was; this can range from establishing a null zone around 0, which is treated as no decision or an *erasure*, to retaining essentially all the information in the correlator output by sufficient finely quantized analog-to-digital conversion (normally three bits), called a *soft* (or *quantized*) *decision*. Schematically, any of these possibilities will be represented by a box following the correlator output labeled A/D.

We can now lay out the complete block diagram of a system that includes coding (Fig. 3). Information bits arrive at a rate of R b/s. An encoder of code rate k/n inserts $n - k$ redundant bits for every k information bits, giving a transmitted bit rate of nR/k b/s. These bits are taken m per baud into the modulator; at the receiver, a noisy correlator output is developed for each baud and A/D converted. The resulting hard decisions, soft decisions, or whatever, enter the decoder, which uses the redundancy in the data as well as (with soft decisions) the reliability of the received information to estimate which information bits were actually sent. When the signal-to-noise ratio is specified, this is a well-defined mathematical model, and it makes sense to ask the question: How much information can we transmit through this channel, and what do we put in the encoder and decoder boxes to do it? The surprising fact upon which we commented at the beginning of this article is that the answer to the first question was announced long before anyone had the remotest idea how to answer the second.

Channel-capacity statements

Shannon's original work[1] showed that the capacity of the communication system blocked out in Fig. 3 is

$$C = \tfrac{1}{2} \log_2 (1 + P/N_oW) \quad \text{bits/baud}$$

$$\text{or } W \log_2 (1 + P/N_oW) \quad \text{bits/second}$$

where P is the received signal power, N_o the single-sided noise spectral density, and W the nominal bandwidth $\frac{1}{2}\tau$. Shannon showed that whenever the information rate R is less than C, then there exists some coding and modulation scheme with as low a decoded error probability as you like; whereas if $R > C$, then the error probability cannot approach zero and more coding generally only makes things worse. Finally, it can be shown that the same results apply when the special modulation assumptions of Fig. 3 are removed, and any signaling scheme whatsoever is allowed.

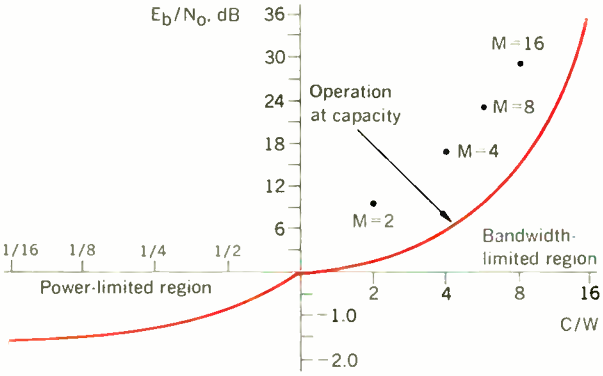
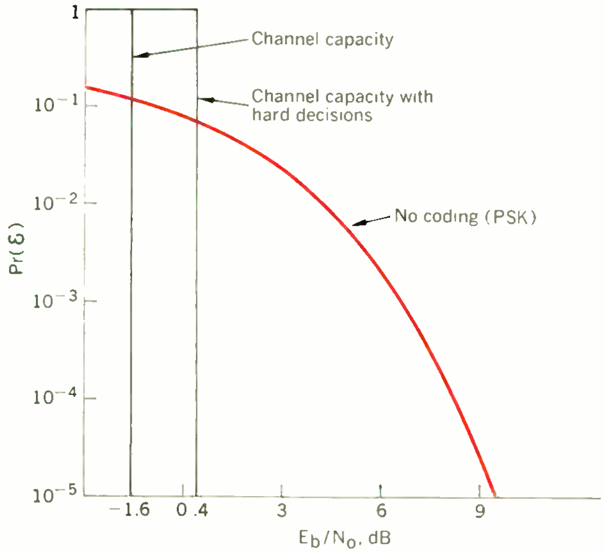


FIGURE 4. E_b/N_o **as a function of C/W in bandwidth-limited and power-limited regions (note change of scale), with operation at capacity contrasted with M-level amplitude modulation [Pr** $(\mathcal{E}) = 10^{-5}$**].**

FIGURE 5. Bit-error probability as a function of signal-to-noise ratio per information bit for situations involving no coding and coding at capacity.



At one time, this classic formula fell into disrepute, after it had been used loosely by all sorts of coarse fellows who applied it promiscuously to channels not remotely characterized by the white-Gaussian-noise model. With the advent of the space channel, however, it is time to rehabilitate it for the insight it provides.

Suppose we could actually transmit at capacity; the signal-to-noise ratio per information bit would then be $E_b/N_o = P/N_oC$. The number of bits per cycle of bandwidth under the same conditions would be C/W. The capacity formula is usefully rewritten as a relation between these two dimensionless parameters:

$$C/W = \log_2 [1 + (P/N_oC)(C/W)]$$

This relation is plotted in Fig. 4. We see that, for a fixed power-to-noise ratio P/N_o, more and more efficient communication is possible as the bandwidth is increased, and that with no bandwidth limitations, E_b/N_o approaches a limit of ln 2 (≈ 0.69, or -1.6 dB), called the Shannon limit. To date, space communication has been characterized by severe power limitation and bandwidth to burn, so that this so-called power-limited case has been the regime of interest. We note that, although the E_b/N_o limit is reached only for infinite bandwidth, at ½ bit per cycle of bandwidth (or a code rate of about ¼ with PSK) we are practically there.

Let us now see what coding has to offer in the power-limited case. Figure 5 is a more standard curve of error probability versus E_b/N_o in decibels. The no-coding curve is that for ideal PSK, which is representative of what was in fact used in the years B.C. (before coding), as in the Mariner '64 system that returned the first pictures from Mars. We see that an E_b/N_o of 6.8 dB is required to obtain a bit error probability of 10^{-3} and 9.6 dB to obtain 10^{-5}. On the other hand, the capacity theorem promises essentially zero error probability whenever E_b/N_o exceeds -1.6 dB. This means that potential coding gains of 8 to 11 dB (a factor of 6 to 12) are possible, which is rather exciting in an environment where the cost of a decibel is frequently measured in millions of dollars. Since, in the power-limited region, R is directly proportional to P, this gain may be taken either as reduced power or as increased data rate.

Another curve of parenthetical interest is included in Fig. 5, the capacity curve when the A/D box of Fig. 3 makes hard decisions. It turns out that this costs a factor of $\pi/2$ or 2 dB. We remark on this loss here because it seems to be one of the universal constants of nature: regardless of the coding scheme, use of hard decisions rather than soft in the power-limited region always costs about 2 dB.

The situation is quite different when the channel is bandwidth-limited rather than power-limited. The following simple argument shows that, in this region, coding no longer offers such dramatic gains. Referring back to the capacity formula, we see that for $P/N_oW \gg 1$, with fixed N_o and W, each increase by a factor of four in P leads to an increase of 1 bit/baud in channel capacity. On the other hand, consider what is required to increase the transmission rate in conventional multilevel amplitude modulation by 1 bit/baud. To double the number of signal levels while maintaining the same level separation and therefore the same probability of error requires increasing the amplitude span of the levels by a factor of two, as in Fig. 6, or the average power P by a factor of about four (this rapidly becomes exact as $N = 2^m$ increases). Thus, if R_{AM} is the rate achievable with amplitude modulation and C the capacity for some power P, then as P increases by k factors of four, we have

$$P \rightarrow 4^k P$$

$$R_{AM} \rightarrow R_{AM} + k$$

$$C \rightarrow C + k$$

$$\frac{R_{AM}}{C} \rightarrow \frac{R_{AM} + k}{C + k} \rightarrow 1 \quad \text{as } k \rightarrow \infty$$

Thus we can nearly achieve capacity without coding as we get deeper into the bandwidth-limited region. In Fig. 4, we plotted the first few AM points for $\Pr(\mathcal{E}) = 10^{-5}$ to show how rapidly R_{AM} approaches C. It therefore may be anticipated that as communications satellites achieve greater and greater effective radiated power the attractiveness of coding will diminish. One also suspects that this argument partially explains why, despite the fact that much outstanding early work on coding, including Shannon's, came out of the Bell Telephone Laboratories, to date there has been negligible operational use of coding on telephone circuits, which are engineered to be high signal-to-noise ratio, narrow-bandwidth lines. Comsat, by inheriting telephone-type tariffs that require its bandwidth to be offered in narrow slices, has been hobbled in the same way.

Maximum-length shift-register codes

In the remaining sections, we will discuss different types of codes and decoding methods, in an attempt to give an impressionistic feel for what they involve, with particular reference to performance on the power-limited space channel. We begin with block codes, which were the first to be studied and have the most well-developed theory. The maximum-length shift-register (or pseudorandom or simplex) codes are a class of codes that make a good introduction to algebraic block codes. Their properties are interesting and easy to derive, and serve as an easy entrée to the mysteries of finite fields, upon which further developments in block codes depend. Furthermore, they are actually useful in space applications and in noncoding areas as well. The number and quality of the pictures of Mars returned from the recent Mariner probes depended on the use of codes like these.

Consider first a digital feedback circuit such as the one depicted in Fig. 7; i.e., an m-bit shift register whose serial input is the modulo-2 (exclusive-or) sum of two or more of the bits in the shift register. In Fig. 7, $m = 4$ and the two bits are the rightmost b_1 and the leftmost b_4, so that the input b_{in} is expressed mathematically as

$$b_{in} = b_1 + b_4 \quad \text{modulo 2} \tag{1a}$$

or, using the notation $\oplus$ for modulo-2 addition,

$$b_{in} = b_1 \oplus b_4 \tag{1b}$$

When we say "shift register," we imply that whenever the circuit is pulsed by a clock pulse (not shown), b_{in} enters the left end, all other bits shift one place to the right, and the rightmost bit b_1 is lost.

It is well to be absolutely solid on the properties of modulo-2 arithmetic before striding off into the woods of algebraic coding theory.* Only two quantities occur in the arithmetic, 0 and 1. They may be added and multiplied as though they were ordinary integers, except that $1 \oplus 1 = 0$. This leads to the curious property that any number (0 or 1) added to itself in this arithmetic "cancels," i.e., equals zero, so that each number can be regarded as the negative of itself, and addition and subtraction are indistinguishable. (For example, if $a = b \oplus c$, then $b =$

I. Modulo-2 arithmetic

Addition

+	0	1
0	0	1
1	1	0

Multiplication

×	0	1
0	0	0
1	0	1

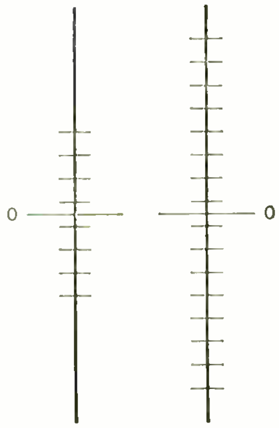
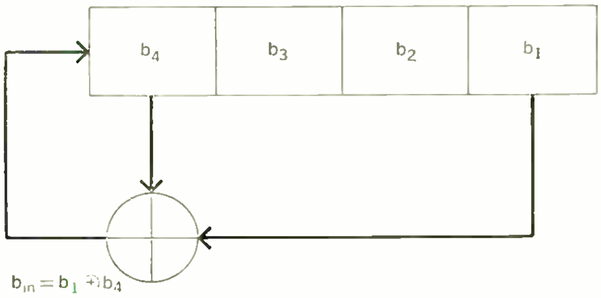


FIGURE 6. **Doubling the number of levels with the same level spacing requires quadrupling the power in pulse amplitude modulation.**

FIGURE 7. **Maximum-length shift-register sequence generator with m = 4 stages.**



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* In general, the operations of modulo-N arithmetic (N equal to any integer) are the same as those of ordinary arithmetic after every number is reduced to its remainder when divided by N. For example, 8 modulo 3 is 2.

$a \ominus c = a \oplus c$.) Addition and multiplication tables are given explicitly in Table I. It is easy to verify that all the ordinary rules of arithmetic—i.e., $a + b + c = c + b + a$, $a(b + c) = ab + ac$, etc.—apply in modulo-2 arithmetic, so that we can manipulate symbolic expressions freely, just as though they involved ordinary numbers, with the additional rule that $a + a = 0$.

Return now to the feedback circuit of Fig. 7. What happens when it is shifted a number of times? The answer clearly depends on what its initial contents are. If all stages initially contain zeros, then the input will be zero, so that a shift will leave the register in the all-zero state. There are 15 other initial states; if we pick one of them, say 0001, and use Eq. (1), we find that 15 shifts cycle the register through all nonzero states and return the register to the starting point. The state diagram is shown in Fig. 8; it consists of two cycles: the one-state all-zero cycle, and the 15-state nonzero cycle. The name "maximum-length shift register" is given to this circuit since, given that 0000 must go to 0000, the 15-state cycle is the maximum length possible.

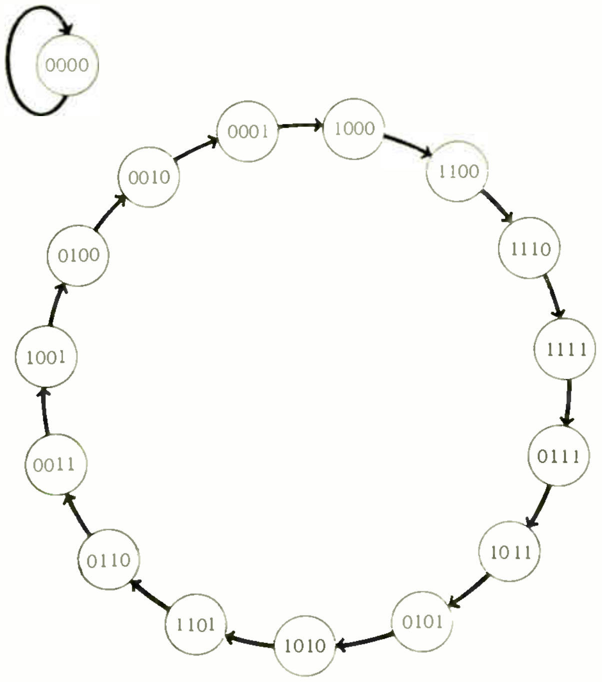
It is a nontrivial result of algebra that for any number of stages m we can always find a circuit like Fig. 7 with a state diagram like Fig. 8. The input is always a modulo-2 sum of certain stages of the register, so the all-zero state always gives a zero input, and the zero state always goes into the zero state on a shift. The remaining $M - 1$ states form a maximum-length cycle, where $M = 2^m$. Table II specifies input connections to the modulo-2 adder that will give a maximum-length shift register for $1 \leq m \leq 34$.

A block code using the circuit of Fig. 7 as an encoder operates as follows: The message to be transmitted, assumed to be a sequence of bits, is segregated into 4-bit segments. Each segment is loaded into the 4-bit shift register, and the register is shifted 15 times. The 15 bits coming out of the rightmost stage of the register are transmitted as a block, or code word. Table III gives the 15-bit code words corresponding to each 4-bit information segment.

This code is called a (15, 4) code, since code words have 15 bits for each 4 information bits. By using registers of different lengths m, we can create $(M - 1, m)$ codes. Since $M = 2^m$, as m gets large, the ratio of information bits to transmitted bits (the code rate) becomes very small, which limits the usefulness of these codes for coding purposes; in other applications, however, the fact that a very long nonrepeating sequence can be generated with a short register is the feature of interest.

We can quickly determine some properties of the $(M - 1)$-bit sequences generated by these registers. First, the bits in these sequences are the rightmost bits of the $M - 1$ nonzero state sequences of length m. Since exactly half of all m-bit sequences end in "1," precisely $M/2$ 1's occur in any maximum-length sequence (for example, 8 bits out of the 15 in the sequence of the example). In a long sequence, if we look at the output at a random time, the probability of seeing a "1" is $(M/2)/(M - 1)$, or just

FIGURE 8. State diagram of feedback circuit in Fig. 7.



II. Connections for MLSR generators

m	Stages Connected to Modulo-2 Adder	m	Stages Connected to Modulo-2 Adder
1	1	18	1, 12
2	1, 2	19	1, 15, 18, 19
3	1, 3	20	1, 18
4	1, 4	21	1, 20
5	1, 4	22	1, 22
6	1, 6	23	1, 19
7	1, 7	24	1, 18, 23, 24
8	1, 5, 6, 7	25	1, 23
9	1, 6	26	1, 21, 25, 26
10	1, 8	27	1, 23, 26, 27
11	1, 10	28	1, 26
12	1, 7, 9, 12	29	1, 28
13	1, 10, 11, 13	30	1, 8, 29, 30
14	1, 5, 9, 14	31	1, 29
15	1, 15	32	1, 11, 31, 32
16	1, 5, 14, 16	33	1, 21
17	1, 15	34	1, 8, 33, 34

III. Code words in a (15, 4) code

Information Bits	Code Word
0000	000000000000000
0001	000111101011001
1000	100011110101100
0100	010001111010110
0010	001000111101011
1001	100100011110101
1101	110010001111010
0110	011001000111101
1011	101100100011110
0101	010110010001111
1010	101011001000111
1101	110101100100011
1110	111010110011001
1111	111101011001000
0111	011110101100100
0011	001111010110010

about ½. Furthermore, since all m-bit sequences except the all-zero sequence occur somewhere in the maximum-length sequence, the probability of seeing a "1" given any $m - 1$ or fewer preceding bits is still nearly one half. These and other statistical properties make a maximum-length sequence difficult to distinguish from a sequence generated truly randomly, as by flipping a coin, yet these sequences are easy to generate and repeatable. Thus they are commonly used to generate pseudorandom bits.

The class of maximum-length shift-register codes is representative of the major classes of algebraic block codes, in that such codes have the properties of being

1. Systematic; that is, the information bits are transmitted unchanged as part of the code word. In the example (Table III), the first four bits of each code word are the information bits.

2. A parity-check code; that is, each of the noninformation (parity) bits is a parity check on (modulo-2 sum of) certain information bits. This can be proved inductively; for example, in the example code, the fifth bit is the modulo-2 sum of the first and fourth; the sixth is the sum of the second and fifth, but this is the same as the second plus the first plus the fourth; in general, the nth bit is some modulo-2 sum of previous bits, which are themselves each modulo-2 sums of information bits, so the nth bit is also some modulo-2 sum of information bits. (In fact, in the maximum-length shift-register codes, the parity bits consist of all possible different parity checks on the information bits.)

3. Cyclic; that is, the end-around shift of any code word is another code word.

The parity-check property can be used to prove the most important single result concerning parity-check codes (the group property), which is that if we form the modulo-2 sum of two code words, we get another code word.

The modulo-2 sum of two n-bit code words is defined as the bit-by-bit modulo-2 sum; that is, if x_i and y_i, $1 \leq i \leq n$ are the bits in the two original code words, then the bits z_i in their sum are

$$z_i = x_i \oplus y_i$$

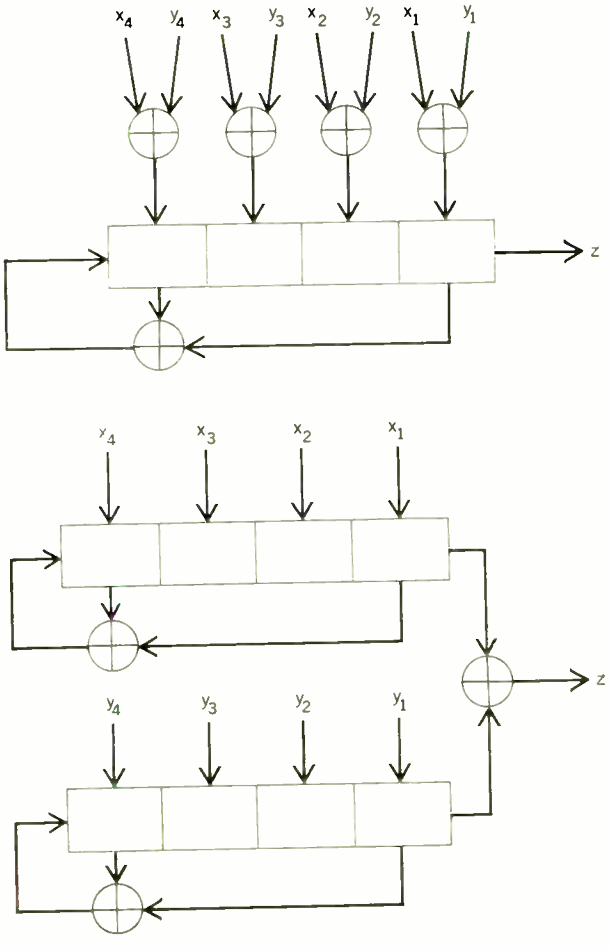
Thus the information bits in z are the modulo-2 sum of the information bits in x and y. The parity bits in z are what we get when we put the modulo-2 sum of the information bits in x and y into our 4-bit register and shift 15 times; it is not hard to see that they are the modulo-2 sum of the parity bits in x and y, since the shift-register connection is itself a modulo-2 sum. In other words, the two circuits in Fig. 9 have identical outputs.

This can be verified also by taking any two of the words in Table III and forming their modulo-2 sum; the result will be another one of the cyclic shifts of the basic sequence.

The group property gives immediate answers to questions about distance or correlation between code words. The distance (Hamming distance) between two code words is defined as the number of places in which they differ. If we form the modulo-2 sum of two code words, the resulting word will have zeros in the positions in which the two code words agree, and ones where they differ; thus the distance between two code words is exactly the number of ones in their sum. But, from the group property, their sum is another code word; and in the maximum-length shift-register codes all words have the same number of ones,* namely $M/2$ (eight in our example). Thus the distance between any two words in these codes is $M/2$, or about half the code length.

The equidistant property of maximum-length shift-register codes makes them an optimum solution to the following problem in signal design: How can one construct M equal-energy signals to minimize the cross-correlation between any two signals, with no bandwidth limitations? Let us suppose that a code word is sent by PSK, so that a 0 is sent as a baud of amplitude -1 and a 1 as amplitude $+1$. The M-code words then correspond to M vectors in $M - 1$ dimensions, all of equal energy (autocorrelation) $M - 1$. The cross-correlation (inner product) of any two vectors is a sum of baud-by-baud correlations, equal to $+1$ if the vectors agree in that place, and -1 if they disagree. But we have just proved that the Hamming distance between any two code words is $M/2$, so that any two vectors disagree in $M/2$ places and agree in the remaining $M/2 - 1$. Consequently, any two vectors are anticorrelated with cross-correlation -1. This implies that as vectors in $(M - 1)$-space, the code words form a geometrical object called a simplex, which is universally believed (though it has never quite been proved) to be the distribution of equal-energy signals in signal space that minimizes the probability of in-

FIGURE 9. Two equivalent linear circuits.



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* Except the all-zero word, of course; this is the code word we get when we sum any code word with itself.

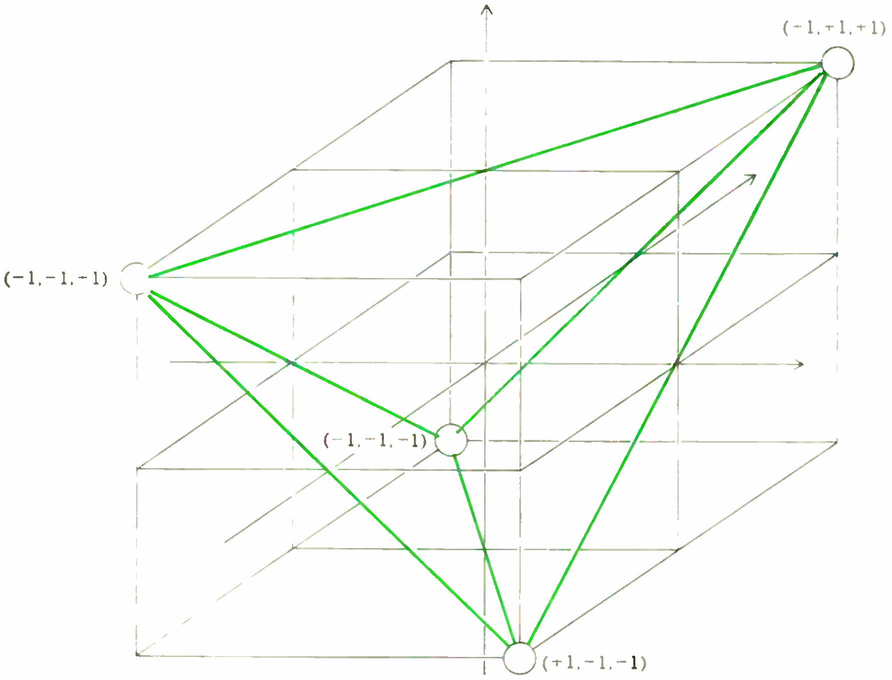
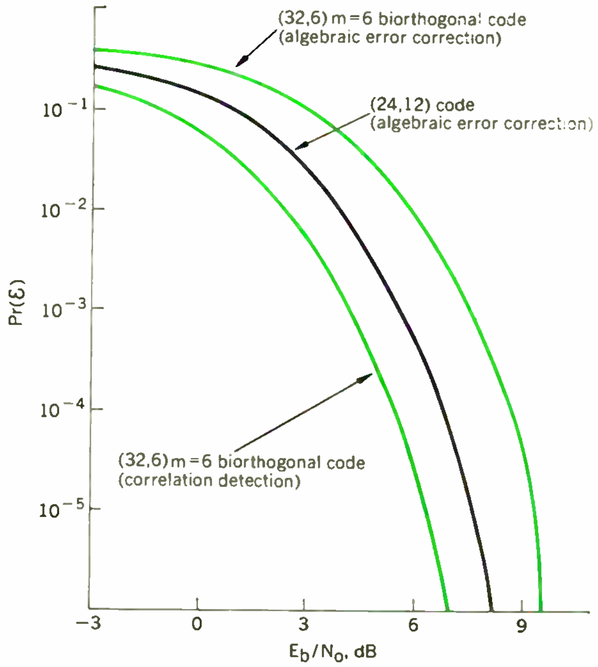


FIGURE 10. Simplex (tetrahedron) formed by m = 2, (3, 2) code in three dimensions.

correct detection. Figure 10 shows the simplex corresponding to the $m = 2$ maximum-length shift-register code, which takes the form of a tetrahedron in three dimensions. Here is an intriguing contact between algebraic coding theory and the geometry of N dimensions.

Suppose now that we use such a binary code with PSK modulation; how shall we decode it at the receiver? As in Fig. 3, we assume that we start with the $M - 1$ correlator outputs z_i that correspond to the $M - 1$ bauds required to send a code word. For definiteness, we use the code of our example in which $m = 4$ and $M - 1 = 15$. Here we shall see a distinction between the viewpoints of the signal designer and of the algebraic coding theorist. The signal designer would take the attitude that what we have here is a way of sending one of 16 signals through a white Gaussian channel, where each possible signal is made up of 15 binary chips, and thus is a vector in 15 dimensions. As in the pure binary case, the optimum detection method is to correlate the received signal against all the 16 possible transmitted signals, which can be done by simply summing the correlator outputs z_i multiplied by ± 1 according to the code word amplitude in the corresponding baud. Thus 16 computations followed by a selection of the largest correlation must be performed. (It turns out that the correlations can be done simultaneously in a special-purpose computer—called the "Green machine" at Jet Propulsion Laboratory[2]—as an M-point fast Hadamard transform, which is structurally very similar to a fast Fourier transform.) The computational load remains manageable for m less than eight or so, which is also where the bandwidth occupied by these codes begins to be absurdly large. A modified (biorthogonal) $m = 6$ code was used in the Mariner '69 expedition; its performance curve is shown in Fig. 11.[3]

FIGURE 11. Performance of various block codes.



An alternate approach is usually taken by the algebraic coding theorist. The first step is to make a hard decision on each correlator output to obtain a 15-bit digital word called the received word. Now we are back in the realm of modulo-2 arithmetic, Hamming distance, and so forth. In the hard-decision process, a number of bit errors will usually be made. From the distance properties of the original code, one can determine that if fewer than some maximum number of errors occur, then correct decoding is guaranteed. In the example, where the Hamming distance between any two words is eight, it is easy to see that if three errors occur in the reception of any code word, then the received word will differ in three places from the correct word, but in at least five places from any other word, so that in principle decoding should be correct. In

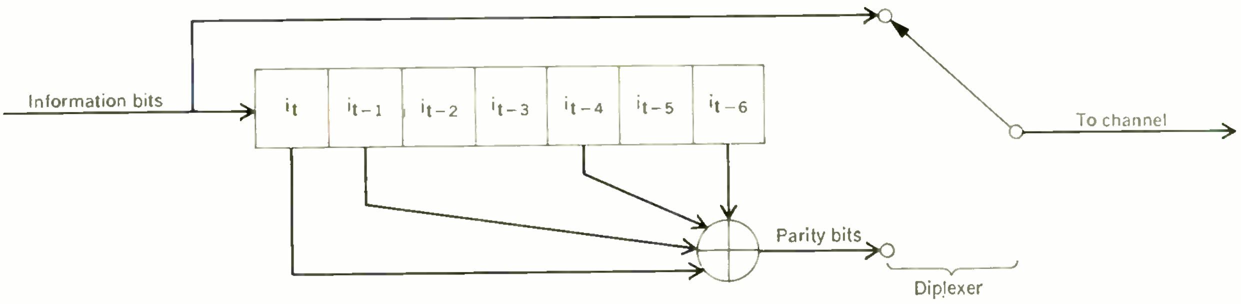


FIGURE 12. Convolutional encoder.

general, a number of bit errors equal to the greatest integer less than half the Hamming distance is guaranteed to be correctable.

One decoding method suitable for the (15, 4) example code is permutation decoding.[4] From the distance properties of this code, we know that if we can find some code word within Hamming distance three of the received word, then we should assume that word was sent, since all other code words must be at least distance five from the received word. To find such a word, we can start by simply reencoding the four received information bits, and checking whether the reencoded parity bits agree with the received parity bits in all but three or fewer places. If so, we are done. If not, then because of the cyclic property of the code, we can take any other four consecutive received bits, treat them as information bits, and generate the rest of the cycle (end-around) that makes up the code. (If this is not immediately clear, try taking any four consecutive positions of any code word in Table III, loading them into the encoder shift register, and shifting 15 times to generate the whole code word, starting at that point and cycling around past the beginning.) If there are actually three or fewer bit errors, at least one set of four consecutive positions will be received correctly, so by taking each set of four in turn, reencoding, and comparing, we will eventually find the correct code word. (This cyclic permutation scheme is also used to correct burst errors, since a correctable burst of errors will not affect at least one set of k consecutive bits.[5])

The performance of hard decisions followed by algebraic error correction is also shown in Fig. 11, for the same (32, 6), distance-16 code as in the correlation detection curve. We see that it is more than 3 dB worse for the lower error probabilities. It might therefore seem that the correlation technique is the better one; however, algebraic decoding remains feasible for much longer code lengths and numbers of information bits, where correlation detection is computationally infeasible. A curve for the (24, 12) (minimum distance eight) extended Golay code is also shown in Fig. 11; with longer codes, the hard-decision disadvantage can eventually be overcome.

Ideally, one would like a scheme whose computational complexity was like that of the algebraic decoding schemes, but would make use of all the information in the correlator output and thus achieve performance like that of correlation detection. At least two approaches (orthogonal equation decoding[6,7] and generalized minimum-distance decoding[8]) with these features are known, but they have not been extensively studied due to the existence of superior convolutional coding schemes (to be described in the next section).

Although we have studied only the maximum-length shift-register codes here, more advanced algebraic block codes involve quite similar ideas. Peterson[9] and Berlekamp[10] are the standard references of the field.

Convolutional codes

Historically, the coding world has been divided between block-code people and convolutional-code people. Although relations between these groups are perfectly amicable, block-code types tend to harp on the relatively primitive theoretical understanding and development of convolutional codes vis-à-vis block codes, whereas convolutional-code types point out that in all respects in which convolutional codes can be compared with block codes they are essentially as good in theory, and in some major respects better, while in practice they are typically simpler. The correctness of both these viewpoints will be illustrated in this section. Whereas we have considered an infinite class of good block codes, we cannot now consider such a class of convolutional codes, since classes of reasonably good codes in the block-code sense are unknown. Instead we shall consider a simple typical code and some reasonable ways of decoding it. The best of these methods will be seen to give better performance on the space channel than any block-code techniques.

Consider the linear sequential circuit illustrated in Fig. 12. Like the maximum-length shift-register generator of Fig. 7, it consists of a shift register and a modulo-2 adder connected to several shift-register stages. In this case, however, information bits are continuously entered into the left end of the register, and for each new information bit a parity bit (a parity check on the current bit and three of those in the past) is computed according to the formula

$$p_t = i_t \oplus i_{t-1} \oplus i_{t-4} \oplus i_{t-6}$$

Information and parity bits are transmitted alternately over the channel. The code generated by this encoder is called a rate-½ convolutional code: rate ½ because there are two transmitted bits for every information bit, convolutional because the parity sequence is the convolution of the information sequence with the impulse response 1,1,0,0,1,0,1, modulo-2. Like the block codes considered earlier, the code is systematic (information bits are transmitted), and is a parity-check code; therefore, it has the group property (the modulo-2 sum of two encoded sequences is the encoded sequence corresponding to the modulo-2 sum of the information sequences).

We shall now suppose that the encoded sequence is sent over a binary channel and that hard decisions are made at the receiver output. How do we decode? First, the decoder must establish which received bits are information and which parity, but as there are only two possibilities, trial and error is a feasible procedure. (For block codes, the comparable problem involves a choice between *n* phases, where *n* is the block length, and some special synchronization means may be required.) This done, we shall let the decoder form *syndromes*, which are defined as follows:

Take the received information sequence, and from it recompute the parity sequence with an encoder identical to that of Fig. 12. Compare these recomputed parity bits with the parity bits actually received; the outputs from the comparator (another modulo-2 adder) are called the syndromes (see Fig. 13). (The syndrome idea is equally useful with block codes.)

It is evident that if no errors occur in transmission over the channel, the recomputed parity bits will equal the received parity bits and all syndromes will be zero. On the other hand, if an isolated error occurs in the parity sequence, then a single syndrome will be equal to one at the time of the error. If an isolated error occurs in the information sequence, then the syndromes will equal one at all times when the incorrect bit is at a tapped stage of the shift register, so the syndrome sequence will be 1,1,0,0,1, 0,1,0,0 . . . , starting at the time of the error. The syndrome pattern for more than one error is just the linear superposition (modulo-2) of the syndrome patterns for each of the individual errors. Thus do the syndromes indicate the nature of the disease.

An obvious technique for correcting single isolated errors now suggests itself. Such an error will manifest itself as a syndrome pattern of 1100101 or 1000000, depending on whether it is in an information or a parity bit. The first time we see a 1 in the syndrome sequence, we know that an error has occurred; the value of the following syndrome tells us whether it was an information or parity error. Since only information errors need be corrected, an AND gate looking for two successive syndrome "ones" suffices, as illustrated in Fig. 14(A).

One can correct double errors with the hardly more complicated circuit of Fig. 14(B). Here the syndromes are fed into a 7-stage shift register; a threshold circuit fires if three or four of four selected places contain ones. The selected places are those that would contain ones if there were only a single information error. A single parity error, in addition, can only disturb one input to the threshold circuit; similarly, it can be verified that with this particular code a second information error can only interfere with one input, so that if only two errors occur the threshold circuit will certainly fire at the right time. On the other hand, it can also be verified that under the assumption of only two errors the circuit will never fire at the wrong time. Finally, the complement line is included to take out the effect of a corrected error in those syndrome bits that were inverted by it, so that the decoder can handle all error patterns that do not have more than two errors in any seven consecutive pairs of received bits.

Both these decoders are examples of threshold decoders[7] (working on a self-orthogonal code[11]). Threshold

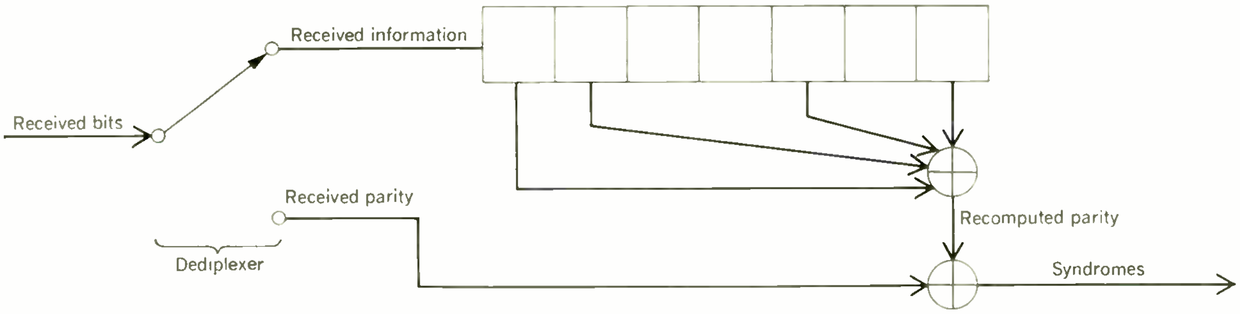
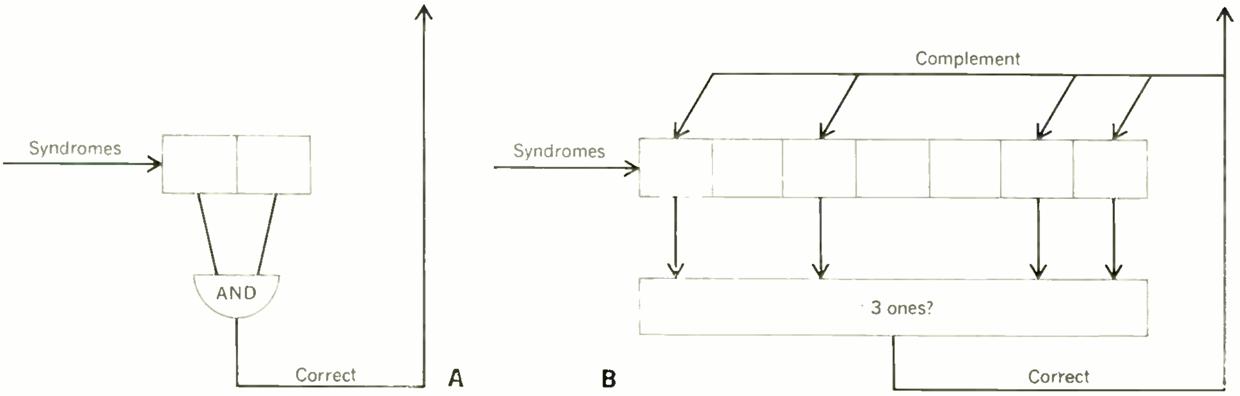


FIGURE 13. Syndrome formation at the receiver.

FIGURE 14. Simple single- and double-error-correcting threshold decoders.



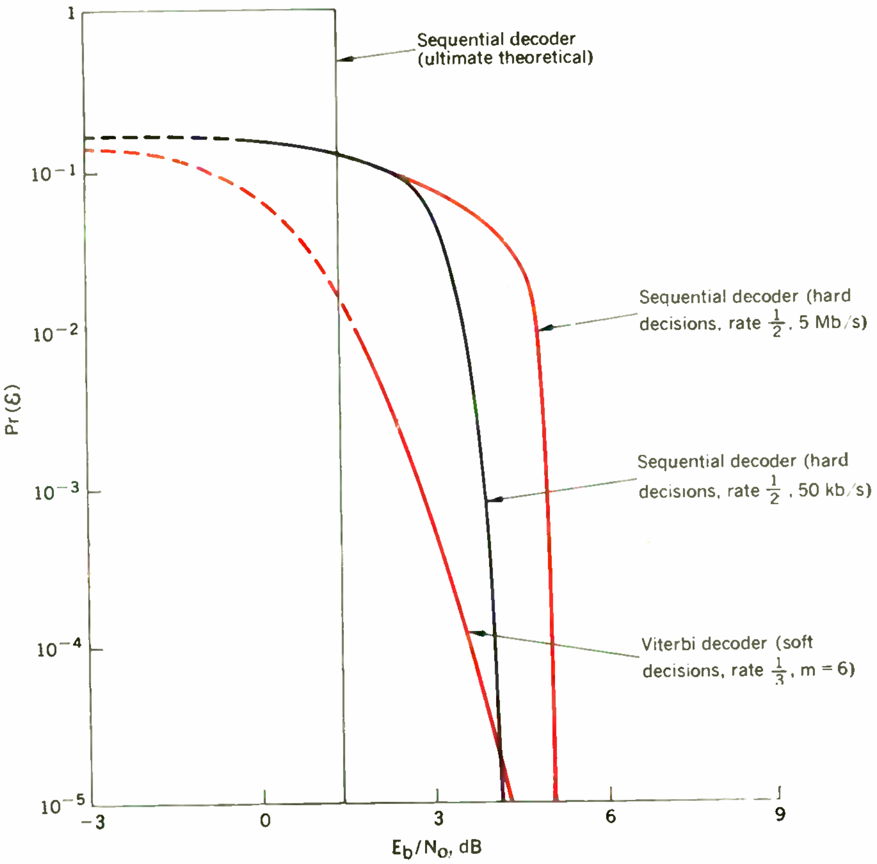


FIGURE 15. Performance of convolutional decoders.

decoding is an extremely simple technique that applies to many short codes correcting a few errors, and that is easily extended to correct bursts of errors. Its efficiency diminishes as the number of errors to be corrected becomes large, and for this reason it is not an outstanding performer on the space channel. With hard decisions, the performance of the three-error-correcting (24, 12) convolutional code (shift register length 12) is about the same (to within 0.2 dB) as that of the (24, 12) block code of Fig. 11.

Sequential decoding was invented by Wozencraft[12] in about 1957. Through a decade of improvement, analysis, and development, it has become the best-performing practical technique known for memoryless channels like the space channel, and will probably be the general-purpose workhorse for these channels in the future. Like much else in the convolutional-coding domain, it is hard to explain and analyze, but relatively easy to implement. Very crudely, a sequential decoder works by generating hypotheses about what information sequence was actually sent until it finds some that are reasonably consistent with what was received. It does this by a backward and forward search through the received data (or through syndromes). It starts by going forward, generating a sequence of hypotheses about what was sent. It checks what was received against what would have been transmitted given the hypotheses, and according to the goodness of the agreement updates a measure of its happiness called the metric. As long as it is happy, it goes forward; when it becomes unhappy, it turns back and starts changing hypotheses one by one until it can go forward happily again. A simple set of rules for doing this is called the Fano algorithm.[13-15]

It is evident even from this meager description that sequential decoding involves a trial-and-error search of variable duration. When reception is perfect, the decoder's first guess is always correct, and only one "computation" (generation of a hypothesis) is required per bit. The more noise, the more hypotheses must be generated, up to literally millions to decode a single short segment. Because of the variability of the computational load, buffer storage of the received data must be provided to permit long searches. Whenever this buffer overflows, the decoder must jump ahead and get restarted, leaving a section of data undecoded. This overflow event therefore leads to a burst of output errors; its frequency generally dominates the probability of decoding error, since the code can be made long enough that the probability the decoder is actually happy with incorrect hypotheses can be made negligible.

Sequential decoding is outstandingly adaptable; it can work with soft or hard decisions and PSK, or with any modulation and detection scheme. In the four implementations for the space channel to date, the Lincoln Experimental Terminal decoder[16] works with 16-ary frequency-hopping modulation and incoherent list detection; the NASA Ames decoder for the Pioneer satellites[17] and the JPL general-purpose decoder[18] work with PSK and soft (eight-level) decisions; and the Codex decoder, built for the U.S. Army Satellite Communication Agency,[19] works with PSK (or DPSK or QPSK) and hard decisions, the choice in every case being based on system considerations. Sequential decoding can even make efficient use of known redundancies in the data, as was done for some preexisting parity checks in the Pioneer data format. The one thing a sequential decoder cannot tolerate is bursts of errors, which will cause excessive computation; therefore, it cannot be applied without modification to any channel but the space channel.

The performance of sequential decoding depends both on the modulation and detection scheme with which it is used, and on the data rate relative to the internal computation rate. The theoretical limit of any sequential decoder on a white Gaussian channel is $E_b/N_0 = 1.4$ dB, exactly 3 dB above the Shannon limit; this limit can be approached with PSK, soft decisions, and low-rate codes. The simplest possible sequential decoder working with rate-½ codes, PSK, and hard decisions has a theoretical limit of $E_b/N_0 = 4.5$ dB; 2 dB of this loss is due to hard decisions, 1 dB to the choice of rate ½ rather than a lower rate. Actual performance depends on the data rate as well as the error rate desired, although the curves are very steep; Fig. 15 shows measured curves at 50 kb/s and 5 Mb/s for the Codex decoder,[20] which has an internal computation rate of 13.3 Mb/s.

Somehow the idea that sequential decoding is complicated to implement has achieved considerable circulation. This is undoubtedly partly due to the difficulty of the literature. Also, the first sequential decoder (SECO[21]), built at Lincoln Laboratory for telephone lines with the technology of an earlier day, was an undoubted monster, due in part to large amounts of auxiliary equipment such as equalizers. It should be emphasized that three of the four implementations just mentioned involve only a drawer of electronics with a core memory system for the buffer storage; the fourth, the Pioneer system, was actually done in software because of the low maximum bit rate (512 b/s).

We conclude by mentioning two more classes of schemes of current interest. One, the Viterbi algorithm,[22] performs optimum correlation detection of short convolutional codes much as the Green machine does of block codes. Figure 15 shows the performance of this algorithm[23] with soft decisions when the decoding complexity is comparable to that of the $m = 6$ block decoder of Fig. 11; performance is uniformly superior. This algorithm is competitive in performance with sequential decoding for moderate error rates, but cannot achieve very low error rates efficiently. On the other hand, it can be implemented in a highly parallel pipe-lined decoder capable of extremely high speeds (tens of megabits) where sequential decoders become uneconomic. It therefore may find application in high-data-rate systems with modest error requirements, such as digitized television.

The second class represents attempts to bridge the final 3-dB gap between the sequential decoding limit and the Shannon limit by combining sequential decoding with algebraic block code constraints. Recent unpublished work of Jelinek gives promise of performances between 1 and 2 dB from the Shannon limit without excessive computation. At the moment, all schemes in this class seem most suited for software implementation, and will probably be used only for low-data-rate applications where the ultimate in efficiency is desired, as in deep-space probes.

Thus do we near practical achievement of the goal set by Shannon 20 years ago.

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Experience curves as a planning tool

The "learning curve"—which relates the direct-labor hours required to perform a task to the number of times the task has been performed—is actually quite general and can be applied effectively to management decision-making

Patrick Conley The Boston Consulting Group, Inc.

Observers have found that the "learning-curve" phenomenon occurs in many complex situations and is not confined to the human learning of repetitive manual skills. If experience improves performance, it should follow that the company that has produced the most widgets will be the most efficient widget producer. This implies that market share is vital in determining potential profitability and that new products, whether developed internally or acquired outside, are doomed to lackluster financial performance unless they capture a dominant market position. The learning-curve effect and its more generalized experience-curve companions are reviewed in this article. Some typical cost and price experience curves are discussed along with the technical details of their derivation. The possible inferences that can be drawn from the observed facts are examined and tested for their qualitative agreement with certain known trends and tendencies.

Any study tool that can help managers understand and predict industry and company trends in price and cost, and that can also help them explain and predict product profitability, is obviously capable of greatly enriching planning. With imaginative application, such a tool can even contribute substantially to unleashing additional profits.

In this article I wish to call attention to what appears to be such a tool and to describe some of its implications and applications for the planning process. Like most tools, its utility lies in its imaginative application. It is no substitute for management, but it can help managers in determining business strategy. Often the very attempt to apply it in a particular situation will lead to new insights into the dynamics of competitive interaction.

The tool is based on the well-known *learning-curve* effect. Since its discovery by the commander of Wright-Patterson Air Force Base in 1925, the interesting "learning" effect has been highly developed and widely used in certain segments of industry.[1-3] The aircraft and electronics industries often use it to guide both their cost control decisions for assembly operations and their pricing policies. The Department of Defense procurement officers use the learning-curve effect in setting cost targets in cost-based contracts.

It is surprising, however, that more companies have not realized the value of the concept. Although it has been observed and applied by the chemical industry and occasionally by other manufacturing enterprises,[4,5] the effect is not always considered by managers in assessing

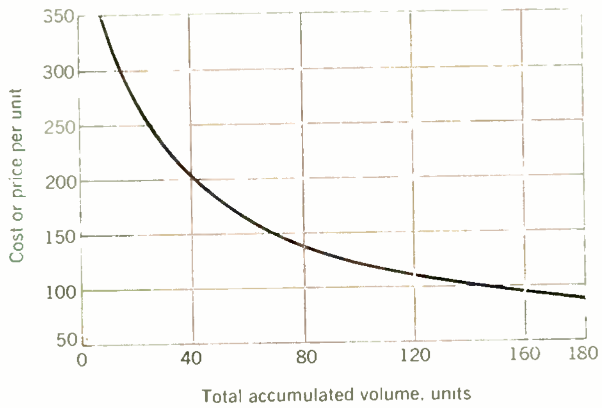


FIGURE 1. Representation of experience relationships graphically on a linear scale.

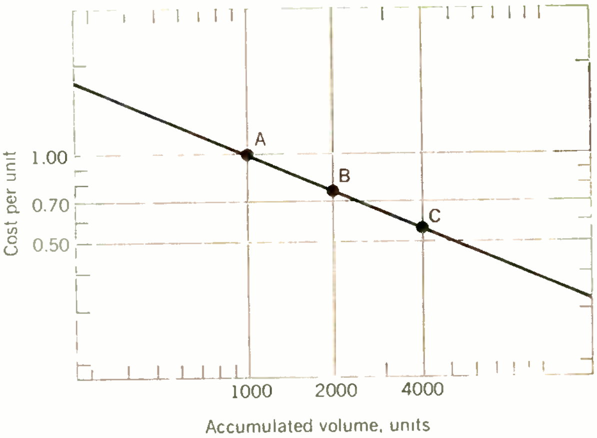


FIGURE 3. Market share and costs for three competitors.

manufacturing performance. It is a vague or totally unfamiliar concept to a surprising number of senior managers who do not have a background in manufacturing or in the defense industry. Unfamiliarity takes on special significance, since the effect appears to depend somewhat on confidence that it exists![3]

In its most common form, the learning curve relates the direct-labor hours required to perform a task to the number of times the task has been performed. For a wide variety of activities, this relation has been found to be of the form shown in Fig. 1, in which time to perform decreases by a constant percentage whenever the number of trials is doubled. Plotted on log-log scales, this relation becomes a straight line with a slope characteristic of the rate of "learning," such as that shown in Fig. 2.

A 20 percent reduction in hours for each doubling of performances—or what is called an 80 percent curve—is typical of a very wide variety of tasks. The concept of continuing improvement "forever," which is apparent in Fig. 2, is often disturbing. However, one must recall that the base of the curve is *not* time but trials and that the number of trials required to make a given percentage improvement grows enormously as learning occurs. Thus, for all practical purposes, learning in most instances eventually becomes so slow that it appears static. If the task lends itself to application of new technology or to partial mechanization, then the slope of the curve can become substantially steeper and 70 to 75 percent slopes are commonly observed.

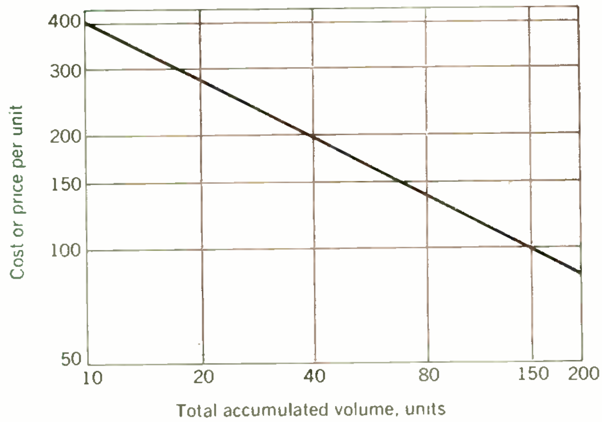


FIGURE 2. Representation of experience relationships graphically on a log-log scale.

The learning-curve effect is not peculiar to manual direct-labor tasks, but is quite general and seemingly applies to most of the activities undertaken within a corporation. In particular, it applies to the start-up of new plants and even to "automated" operations.

Cost as a function of learning

Since learning increases the efficiency of an operation, it naturally reduces the cost of that operation. This fact has frequently been used for estimation and prediction.[5] In fact, observers have noted that costs go down *by a fixed percentage* each time the number of units produced doubles. Recent studies by The Boston Consulting Group serve to augment these observations. There is every reason to believe that each element of cost declines in such a way that total cost follows a composite learning curve.

In computing the precise relationship between costs and learning, one must be alert to certain factors that can distort the picture. If costs are measured in dollars, it is necessary to eliminate inflation when observations are made over a substantial period of time. Deflation of cost figures thus becomes more important when growth rates are slow, so the doubling of trials or units requires several years. One might also argue that material costs, when large and fixed, should be removed and the learning effect applied only to the value added. However, removing material costs turns out to be a relatively minor correction in most instances; in other instances, these costs are themselves subject to reduction through substitutions ("learning?"). Consequently, we will neglect the value-added refinement in our subsequent considerations.

The fact that the total cost of many products declines by a fixed percentage each time the cumulative number of units produced is doubled has been widely recognized and used for cost prediction and control.[3,6] However, cost data are usually proprietary and always mechanically difficult to obtain for individual products, so

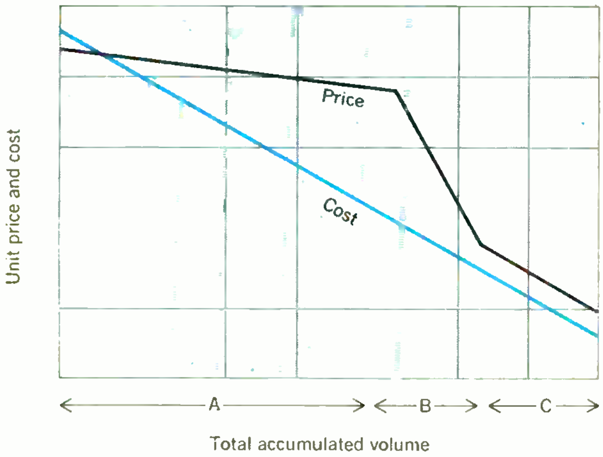


FIGURE 4. A characteristic pattern of costs and prices.

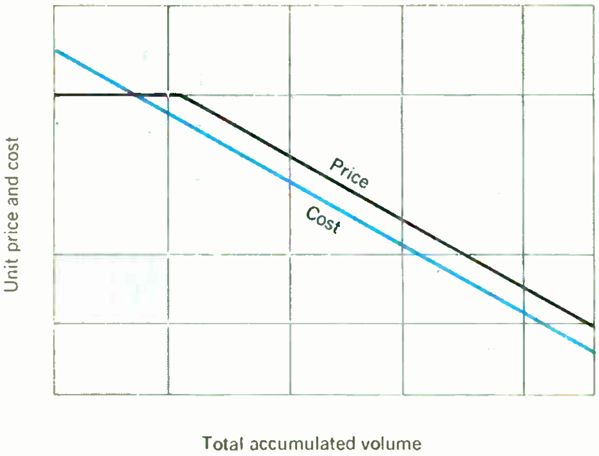


FIGURE 5. An alternative pattern of costs and prices.

research on the subject requires a high degree of cooperation and assistance on the part of the manufacturer. A common problem encountered when one examines the historical cost of a particular product is a series of discontinuities in the data. The discontinuities are usually associated with changes in accounting methods and are expensive and tedious to rationalize. Also, since we are considering *total* costs, the method of allocating indirect costs becomes a factor in multiproduct companies, and traditional allocations may have to be adjusted to achieve the desired precision.

Costs and market share

In spite of long-standing awareness of the learning-curve phenomenon and its effect on costs, the obvious strategic implication seems until now to have been ignored. If cost declines predictably with units produced, the competitor who has produced the most units will probably have the lowest cost. Since the products of all competitors have sensibly the same market price, the competitor with the most unit experience should enjoy the greatest profit. Furthermore, it should be clear that very substantial differences in cost and profit can exist between competitors having widely different unit experiences. Of course, this assumes that all competitors have equal access to resources and patents and that the competitors are all reasonably efficient.

Over a period of time when market positions are relatively stable, experience can be equated with market share. Thus market share and profitability are closely related, and competitive positions can become those shown in Fig. 3. In the exhibit, competitor A is the marginal competitor, whereas competitor C dominates the market. Empirically (and perhaps theoretically), the market share of the dominant competitor in a stable, slowly growing market turns out to be about 50 percent. The next competitor typically has 25 percent; the third has 12 percent, and so on.[7] The 50–25–12 percent share distribution observed by Cohen may result more from a subconscious agreement among competitors than from the operation of random influences. In a mature market, stability is often in the best interest of all the competitors.

If the market is growing rapidly—say 15 percent or more annually in units—then market shares may be fairly fluid, and the dominant producer may have much more or even less than 50 percent of the market.

Price and experience

Assuming that costs can be made to decline at a predictable rate such as that shown in Fig. 2, we can examine the related price curves for possible correlation. In general, we find most price curves to have either the form shown in Fig. 4 or that shown in Fig. 5, with a strong predominance of the former type. In these idealized examples, as well as in the actual ones to be discussed later, we are plotting industry unit price (or weighted average unit price if several sizes or grades are involved) against total historical industry units on logarithmic scales. The costs shown are average industry costs, weighted by the unit production of each competitor. (If these prices are plotted with appropriate costs for the individual competitors' experience, the slope of the price line will *appear* to vary if the competitor is gaining or losing market share substantially.)

In Fig. 4, the constant-dollar price shows little or no decline during phase A, a steep slope of around 60 percent in phase B, and a moderate 70 to 80 percent slope in phase C. The relatively level price exhibited in phase A is associated with the introductory period in which price is set somewhat below initial cost and not changed as volume grows. If this price is held too long, competitors enter, and all add capacity until a "shakeout" price decline occurs in phase B. When prices reach a "reasonable" level above costs, they continue to decline with cost, as shown in phase C.

Characteristically, the dominant producer is losing his share of the market during phase A. During phase B, market shares may shift considerably as the more aggressive competitors struggle for dominance, using price as a major weapon. In phase C a stable competitive situation is again established with possibly a different dominant competitor than the one in phase A.

In Fig. 5, the price is brought down more nearly in parallel with cost—usually in an attempt to discourage the entry of competition. Although initial margins are less, final margins are usually greater.

There is nothing inherent in the price characteristics shown in Figs. 4 and 5 that reveals one to be "better" than the other. One might expect a wide variety of patterns between the two types shown; however, such variation does not appear to occur in practical instances.

It must be remembered that these idealized curves are typical of those obtaining in uninhibited competition and are exclusive of the influences of inflation. One must also be certain to avoid thinking of them as plots against *time*. Although time increases with experience, the curves are plotted against *units produced* and may be quite irregular with respect to time.

Observations of price behavior

Price data are relatively easy to acquire and, when adjusted by means of the GNP deflator,* they can be plotted as shown in Figs. 6 through 10. These exhibits are typical of many, many similar ones for a very wide variety of products. Figures 6 and 7 show the two classical forms of price behavior in semiconductors. Figure 8 is considered typical of the chemical industry. Figure 9, for facial tissues, has an unusual break in the price pattern. This break shows what happened when an element in the distribution chain was omitted and the factory picked up the eliminated unit's markup. Figure 10 shows the behavior of a very slowly growing product, free-standing gas ranges, over a very considerable period. In all of the cases, the data points in any one graph refer to equal intervals of *time*. Obviously, strong underlying laws are at work.

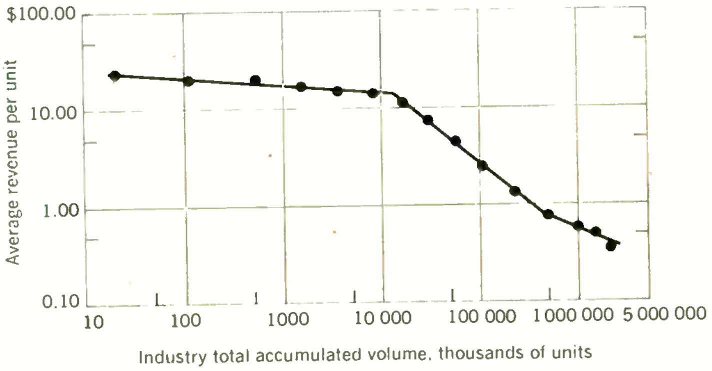
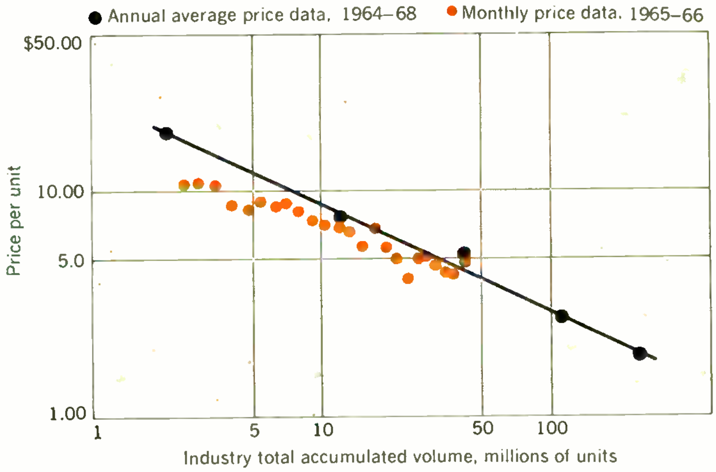


FIGURE 6. Revenue curve for silicon transistors during the period from 1954 to 1968.

FIGURE 7. Price curve for integrated circuits.



The 1965–1966 data for integrated circuits in Fig. 7 are particularly remarkable, since each point represents an average *monthly* price. The clustering of points, shown strongly in the progressive data at the high-volume end of Fig. 9, is indicative of declining growth rate in the product. Such a decline (with its resulting cluster) is often the precursor of a price break when it occurs in the location of phase A of Fig. 4.

From the data shown, as well as from the long-acknowledged behavior of costs, one can conclude that prices behave in a remarkably predictable and regular manner and that, in constant dollars, prices tend to decline. Break points are perhaps difficult to foresee, but they are associated with declining growth rates in the presence of a price "umbrella." Once again, the plots are in terms of total units produced and not in terms of time

Product strategy implications

Since prices and costs tend to decline with units produced and since the producer with the largest stable market share eventually has the lowest costs and greatest profits, then it becomes vital to have a dominant market share in as many products as possible. However, market share in slowly growing products can be gained only by reducing the share of competitors who are likely to fight back. It may not be worth the cost to wrest shares away from competent competitors in low-growth products. The value—in terms of improved cost and increased volume—of an increase in market share can be calculated with the aid of the experience curve. The investment required to increase one's share in the market can be compared with the calculated value, and, after suitable allowances for risk factors, the decision can be made. The company should remember, however, that most competitors will price at out-of-pocket cost rather than close a facility.

But all products at some time enjoy a period of rapid growth. During rapid growth, a company can gain share by securing most of the *growth*. Thus, while competitors grow, the company can grow even faster and emerge with a dominant share when growth eventually slows. The competitors, pleased with their own growth, may not stage much of a contest even when the company is compounding its market share at their eventual expense. At high growth rates—say 20 to 30 percent in units—it is possible to overtake a competitor in a remarkably few years.

The strategic implication is that a company should strive to dominate the market, either by introducing the product, by segmenting the market, or by discouraging competitors' growth in rapidly growing areas by preemptive pricing or value. Developing and introducing new products, though a good road to dominance, involve considerable cost and uncertainty. Similarly, it is difficult to identify a market segment that can be isolated from those segments in which competitors have more experience and lower costs. However, the history of business abounds with examples of successful segmentation. The key is to find a segment the company can protect

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* The GNP deflator is a factor used to correct prices for any given year to what they would have been in the base year by removing the average inflation in the gross national product. See Ref. 8.

over a long period of time. In contrast, the idea of preempting market by price or value concessions is intuitive in most business organizations. Although price competition is usually resisted, it is often cheaper than the more intangible weapon of added value.

The product portfolio

The products of a firm can be categorized into four groups in terms of market share and growth rate. Table I depicts such a matrix.

Category 1: Products with a high market share but with low growth. Products in category 1—those whose growth is equivalent to the growth rate of the GNP—are *not* attractive areas for investment, but they are the main source of reported earnings and cash. They are usually products for which a dominant market share is held. Their good earnings are sometimes used inappropriately to justify continued investment in the hope that growth can be increased, whereas the proper objective is to maximize cash flow consistent with maintaining market share.

Category 2: Products with a high market share and rapid growth. Products in category 2 are those that, if dominant share can be maintained until growth slows, will become the high dollar earners of category 1. These products are heavy consumers of cash and earnings, and those for which leading market position must be maintained. To attempt to extract high earnings from these products during their growth phase will usually blight the growth and sacrifice the dominant position. If continued until growth slows, such "bleeding" will move the product into category 4 instead of into category 1.

Category 3: Products with a low market share, but rapid growth. Category 3 includes products in which a dominant market share must be achieved before growth slows, or a marginal position will be "frozen in." These products demand a heavy commitment of financial and management resources. Since such resources are limited, the number of such products in the portfolio must be limited. If resources are not available to move a product in this category into a dominant market position, then it is usually wise to withdraw from the market.

Category 4: Products with low market shares and slow growth. The final category comprises the "dogs"—products that consume far more than a just amount of management attention. They can never become satisfactorily profitable and should be liquidated in as clever and graceful a manner as possible. Outright sale to a buyer with different perceptions can sometimes be accomplished. Often pricing in a manner to upset competitors is a useful adjunct to liquidation. In any event, investment in such areas should be discontinued.

It is useful to examine a corporation's products and try to classify them into the foregoing categories. Lack of balance becomes rapidly evident and plans can be laid to add and drop products to achieve a more nearly satisfactory portfolio. It must be remembered that we are talking of products, not industries, although some industries are sufficiently simple in product diversity that they behave as single products.

An unbalanced product portfolio produces some typical cash-flow symptoms. If the company has too many dominant, slow-growth products, it will usually have a low growth rate coupled with excess cash and inadequate investment opportunity. Having too many high-growth products will produce cash deficiencies as well as rapid growth. Too many low-share, low-growth products will result in inadequate cash *and* inadequate growth. With

I. Product growth and market share

	High Market Share	Low Market Share
High growth rate	category 2	category 3
Low growth rate	category 1	category 4

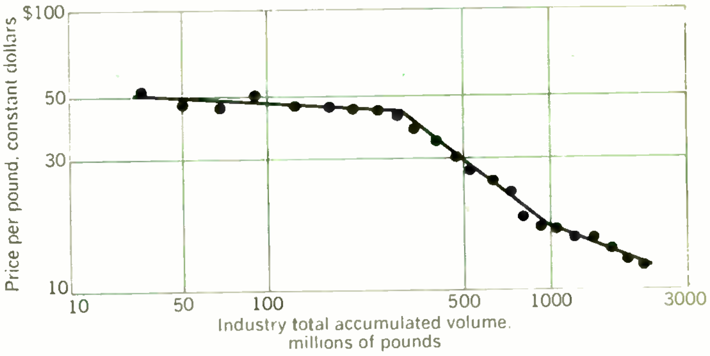


FIGURE 8. Polyvinyl chloride price curve (1946–1968).

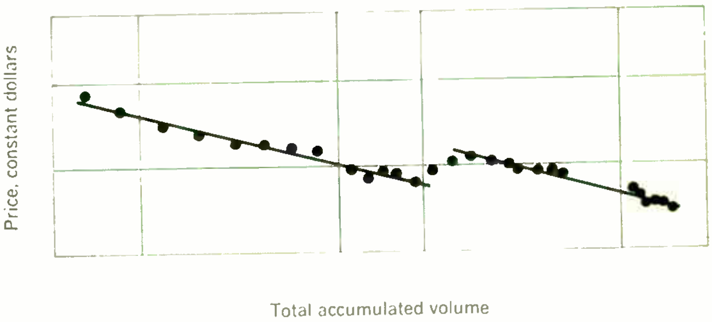
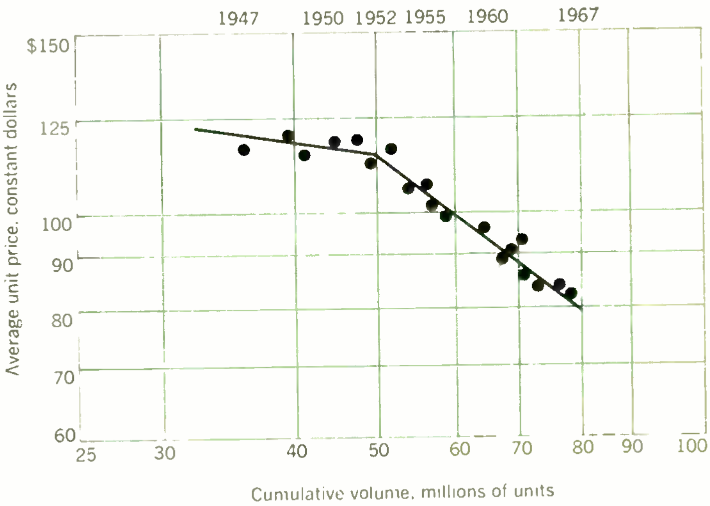


FIGURE 9. Price curve for facial tissues (for the years 1933–1955 and 1961–1966).

FIGURE 10. Price curve for free-standing gas ranges.



time, the balance of a product portfolio will automatically change if no deletions or additions are made.

Control implications

Market dominance by product is the key to profitability and it can be achieved by expenditures and investments during the rapid-growth phase for a given product. The source of the funds should be mature or slowly growing products in which dominance has already been achieved and in which expense and investment are no longer intense. It is important to avoid control procedures that stifle the rapid-growth phase; yet when growth slows, it is vital to secure maximum cash flow and avoid investment overshoot.

Budgeting and control systems should be quite different for the two categories, and different objectives should be set for the product managers. Clearly, the main objective in managing the rapidly growing product should be market penetration, whereas the goal for the dominant mature product should be to maximize cash flow. In both cases the total costs should be managed to follow the experience-curve slope appropriate to the industry. A control system that sets appropriately designed goals for market share, cash flow, and cost progress is more likely to produce continuing growth in reported earnings than a system that merely stresses product-line profitability.

To use the experience-curve effect in the control system and the management decision process, the company must have comprehensive data on costs and market share. If such data can be obtained, the company will have a powerful tool.

Needless to say, the successful implementation of a competitive strategy also depends upon the reaction of competitors. The route to a dominant share of a growing market lies in discouraging competitors from adding capacity or increasing their capability to produce the product. An estimate of the key competitors' decision processes is thus invaluable in planning competitive interaction.

Forecasting

The use of the experience curve to forecast prices—both for products and for purchases—is obvious. Again, one must use care to deflate the raw data and reinflate the forecast. Use of the GNP deflator has been most satisfactory and, in particular, better than the sector deflator.* (If the sector deflator is used, one is likely to erase evidence of the effect sought.) Obviously, the resulting forecast carries a forecast of inflation rate that is included in the deflator projection.

The forecast of price-break points is much more difficult than projecting an existing trend—even in the presence of strong inflation. If capacity in the industry seems high and if prices appear soft, it may be wise to initiate the break, since the leader in a severe price decline usually is the gainer in market share.

Conclusions

The fact that manufacturing costs tend to follow an experience curve not only is useful for cost control and forecasting but also has a profound implication for prices and profits. In particular, it is strongly suggested that the producer of a particular product who has made the most units should have the lowest costs and highest profits. The potential profitability of a mature product should be closely related to the market share it enjoys in its particular segment.

The products of a company can be grouped by market share and growth rate in order to prescribe appropriate management of products in each group. Substantially different management objectives should be pursued in each of the four categories described. The important strategic issues of product selection, price policy, investment criterions, and divestment decisions can be more effectively addressed in the context of the experience curve than in other ways—*even if no actual data are ever collected or actual curves plotted.*

Essentially full text of a paper presented at a meeting of the Chemical Marketing Research Association, Houston, Tex., Feb. 23–24, 1970.

The concepts and observations described briefly here have been developed over several years in a series of discussions among staff members of The Boston Consulting Group under the leadership of Bruce D. Henderson. The efforts of all the members of the group are hereby acknowledged with great appreciation.

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Patrick Conley (SM) received the B.S. degree in electrical engineering from Rice Institute, the M.S. degree in communications engineering and Ph.D. degree in applied physics from Harvard University, and the M.B.A. degree with high distinction from Harvard Business School, where he was a Baker Scholar.

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* The sector deflator is a correction factor to be applied to prices in a particular sector of the economy—for example, chemicals—to adjust for the inflation that has occurred in that particular economic sector.

Desensitization of dc power supplies to momentary ac power fluctuations

The output capacitor in a dc power supply may enable the unit to span momentary ac power-line disruptions. However, the best assurance against such interruptions is provided by a separate energy-reservoir circuit

K. T. Huang *U.S. Naval Civil Engineering Laboratory*

At the present time, dc power supplies generally are not designed to maintain continuous and steady voltages during momentary disturbances in their ac power-transmission-supply line. Yet, during lightning storms, or through some line fault, electrical disturbances can occur within transmission lines that tend to depress dc power-supply voltages. There are methods for desensitizing the dc power supplies to these ac disturbances. One way—if the power supply does not make use of SCRs—is to use larger capacitors in the rectifier circuit. In any event, and especially if SCRs are used, the best method for sustaining dc output power is to use an auxiliary energy-reservoir circuit.

The rudimentary function of the dc power supply is to receive energy from an ac source, store that energy, and then release it as required by the load. If the ac source fails abruptly, the dc output will drop—not suddenly, but exponentially—as the quantity of stored energy is gradually siphoned by the load. The time that it takes for the energy to deplete obviously depends on the size of the capacitor storing the energy, the amount consumed by the load, and the minimum voltage required by the load.

It is not unusual for momentary ac power disruptions to occur—as they might during a lightning storm or during frequency adjustments at the power station. If the disruption is brief enough, the stored energy in the power supply may be ample to smooth over any effect on the dc voltage to the load. The trouble is that design engineers ordinarily don't purposely incorporate the size of capacitor into power supplies that maintains dc output voltages when the ac power momentarily fails.

If the power supply is based on a basic bridge rectifier–capacitor circuit it, of course, is possible to improve the dc output stability in the event of an ac disruption—within certain economic limitations imposed by the rectifiers—by increasing the size of the output capacitor. A better solution is to insert a separate energy-storage section into the power supply. In fact, for more sophisticated dc power supplies, such as those that make use of variable-phase-angle-firing SCRs, adding a separate energy-storage section is the only practical way to "ride out" the ac disruption.

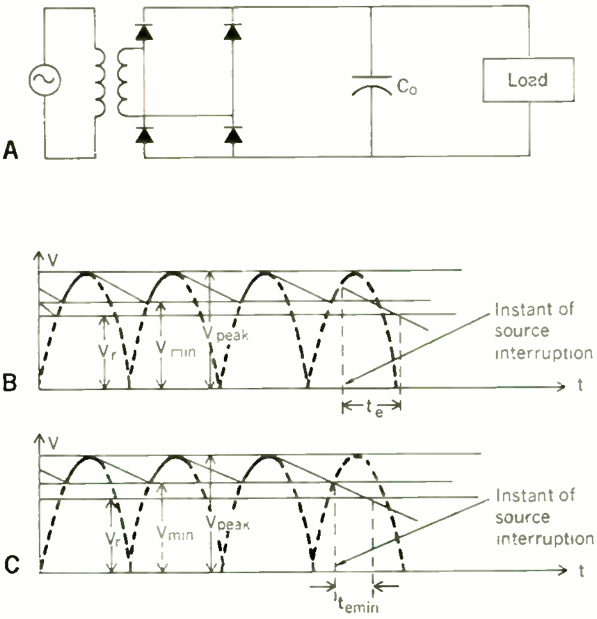
To understand why this is so, it is necessary only to analyze some circuit configurations.

Basic circuits

A bridge rectifier and a capacitor connected as shown in Fig. 1 form a basic configuration for converting ac voltage to dc voltage. The energy-storing capacitor, C_o, stores and supplies energy to the load. If the ac source is interrupted, the dc output voltage decays exponentially to zero. To illustrate, choose an arbitrary voltage, V_r, as the minimum value required to maintain load operation. The time, t_e [Fig. 1(B)], is the duration between the instant that ac power is lost and the dc output voltage reaches V_r. The useful charge, Q_u, on capacitor C_o that extends t_e is given by

$$Q_u = C_o(V_{\text{inst}} - V_r) \qquad (1)$$

FIGURE 1. A—Basic dc power-supply circuit. B—Associated output-voltage waveform when ac power is interrupted at a level greater than $V_{\min}$. C—Associated output-voltage waveform when ac power interruption occurs at $V_{\min}$.



where V_{inst} is the instantaneous voltage across capacitor C_o at the time the ac source is interrupted. The time duration, t_e, is given by

$$t_e = \frac{Q_u}{I_{\text{dc}}} = \frac{C_o(V_{\text{inst}} - V_r)}{I_{\text{dc}}} \tag{2}$$

where I_{dc} is the dc load current. The shortest t_e results if the ac source is interrupted when the instantaneous voltage across capacitor C_o is V_{min} [Fig. 1(C)]; then Eq. (2) becomes

$$t_{e\text{min}} = \frac{C_o(V_{\text{min}} - V_r)}{I_{\text{dc}}} \tag{3}$$

Equation (3) shows that when I_{dc} is fixed, $t_{e\text{min}}$ is extended by increasing C_o. Although increasing C_o also raises V_{min} and, therefore, the quantity $V_{\text{min}} - V_r$, the increase in C_o is dominant in increasing Q_u, hence, $t_{e\text{min}}$.

Figure 2 shows the increase in t_e obtained by using a larger C_o. Curve 1 is for the large-valued capacitor C_o.

Figure 3 compares the lengthening of t_e in a series-regulated transistor, dc power-supply circuit with a C_o of both 450 and 4450 μF.

Even though a simple method of extending t_e is to increase C_o there are factors that limit the size of the energy-storing capacitance.

When selecting a larger-valued capacitance, it becomes necessary to examine the rise in rectifier cost against the extension of t_e obtained. With increasing capacitance, the ratio of initial turn-on current to rated load current increases. This necessitates operation of larger rectifiers at increasingly derated condition, which is economically inefficient. Also, a larger-valued capacitance increases the response time of the dc power supply thereby lengthening the flow duration of the turn-on current. Longer flow duration contributes to rectifier failure from heating.

SCR supply

Figure 4(A) is a circuit diagram of a basic silicon controlled rectifier (SCR) dc power supply. The dc output voltage level is controlled by the "variable-phase-angle-firing" technique, which provides a partial full-wave rectified waveform and requires a very large capacitance to obtain a "smoothed-out," limited-ripple waveform; therefore, unlike the transistor-regulated dc supply circuit, the SCR circuit is not amenable to significant increase in t_e by the mere increase of capacitance. This fact is displayed in Fig. 4, which illustrates the limited-ripple voltage obtained by using a (large) capacitor, C_o. It also shows the extended duration t_{e_1} obtained with the loss of the ac power source. Increasing the capacitance reduces the ripple, as shown in Fig. 4(C), but $V_{\text{min}} - V_r$ is essentially unchanged and duration t_{e_2} increases slightly.

The limitations on extending t_e in a basic dc power-supply circuit are more severe in a power circuit using SCRs instead of transistors. With either circuit, however, it is possible to supplement the Q_u available in the basic power-supply circuit—and thus t_e—with an energy-reservoir circuit such as the one shown in Fig. 5(A).

The basic principle of this circuit is to charge an energy-storing capacitor at a high voltage and release this energy to the load during momentary ac power loss. The energy storing C_{aux} is charged rapidly to its peak capacity during normal operations of the ac power source. The reservoir circuit remains on standby status and consumes very little power. At the instant of ac power loss, the reservoir circuit supplies Q_{aux} to supplement Q_u and maintain V_o throughout the outage. The capacitance C_{aux} can be calculated by modifying Eq. (3):

FIGURE 2. Comparison of output-voltage decay for different values of the energy-storing capacitor in a basic dc power supply.

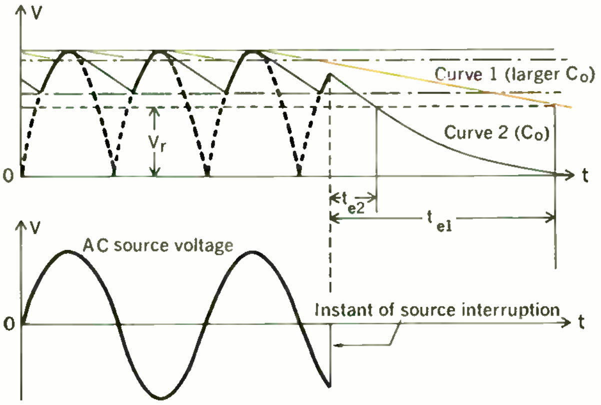
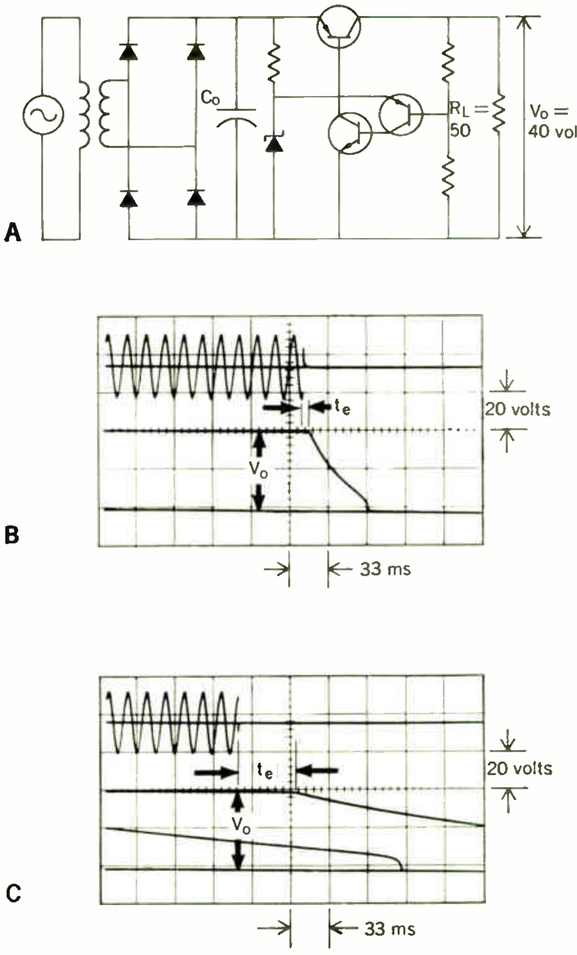


FIGURE 3. A—Schematic of a series-regulated, transistorized dc power supply. B—The duration time, t_e (see text), for an output capacitance of 450 μF. C—The duration time for an output capacitance of 4450 μF.



$$C_{aux} = \frac{I_{dc}(t_e - t_{mi})}{(V_h - V_r)} \tag{4}$$

where t_{mi} is the extended duration of dc voltage without insertion of the energy reservoir circuit; and V_h is the peak value to which C_{aux} can be charged.

The current limiter in the auxiliary circuit is used to (1) prevent damage to the rectifier D_1 by the initial charging current and (2) protect the active elements in the control circuit from the high current from the rectifier transformer during a malfunction of dc power supply.

During the initial charging, the voltage of C_{aux} usually is lower than the output voltage, V_o. Rectifier D_2 is used to prevent damage to transistors Q_1 and Q_2 from the current flowing from point 3. The voltage difference, $(V_h - V_r)$, determines the selection of the maximum rating of V_{ce}, the voltage of the power transistor Q_1. The comparison circuit is present to sense the voltage drop and to furnish the actuating signal to operate the control circuit. The sensing voltage should be adjusted in such a position that the energy-reservoir circuit remains on standby status in normal operation. The control circuit adjusts the flow rate of Q_{aux} as required by the load to maintain the output voltage.

The energy-reservoir circuit is connected to the basic power supply as shown in Fig. 5(B). The reservoir circuit offers considerable latitude in the selection of the value of the energy-storing capacitance and the operating voltage. This flexibility is not offered in the basic dc power-supply circuit because the required output voltage fixes the voltage across the energy-storing capacitor, C_o; the method of obtaining the larger Q_u is limited to increasing C_o and a larger C_o is accompanied by undesirable effects, such as excessive inrushing of turn-on current.

The power ratings of the components in the reservoir circuit can be modest because the average power is low, although the peak energy delivered momentarily may be appreciable. The auxiliary reservoir circuit, even with the use of a large energy-storing capacitor C_{aux}, does not reduce the response time of the basic power supply because the one is independent of the other.

Figure 6 compares the time-extending characteristics obtained in a transistorized shunt-regulated power-supply circuit either by simply adding a capacitor or by using the additional capacitor with an auxiliary energy-reservoir circuit: The addition of a capacitor extends the time by 12 ms. With the auxiliary circuit, using the same value of capacitor, the time is extended by 38 ms.

DC power supply

The KGP-5 (T-1)/TSEC dc power supply shown in Fig. 7 has four dc outputs: one +6 volts, two −18 volts, and one −7.5 volts. The 6-volt output consists of an *LC* filter and a transistorized shunt regulator; the total direct current (including load- and shunt-regulating current) is 0.5 ampere; the −18-volt(b) output consists of an *RC* filter and a Zener shunt regulator with total direct current of 1 ampere; the −18-volt(a) output consists of a two-section *LC* filter and an SCR unregulated supply with a 5-ampere load; the −7.5-volt output uses an *RC*

FIGURE 4. A—Circuit diagram for an SCR power supply. B—Waveform outputs using "standard" output capacitance. C—Waveform outputs for an increased value of output capacitance. Note only small effect of capacitance change on t_e.

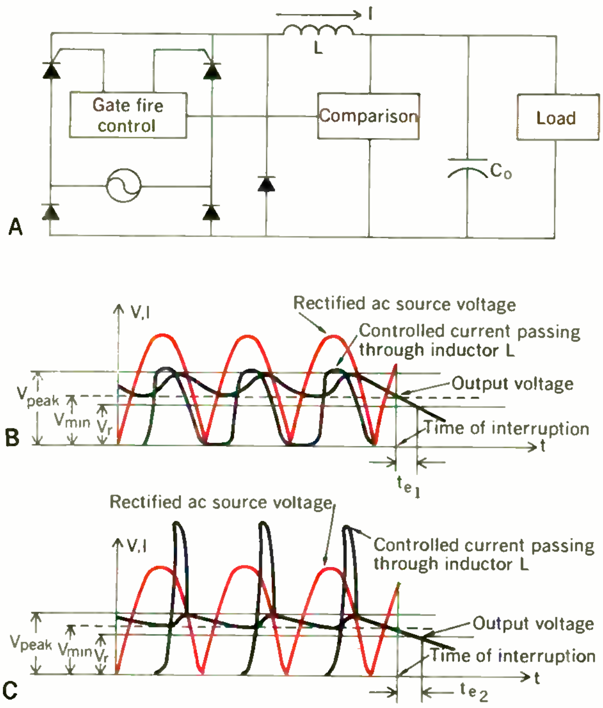
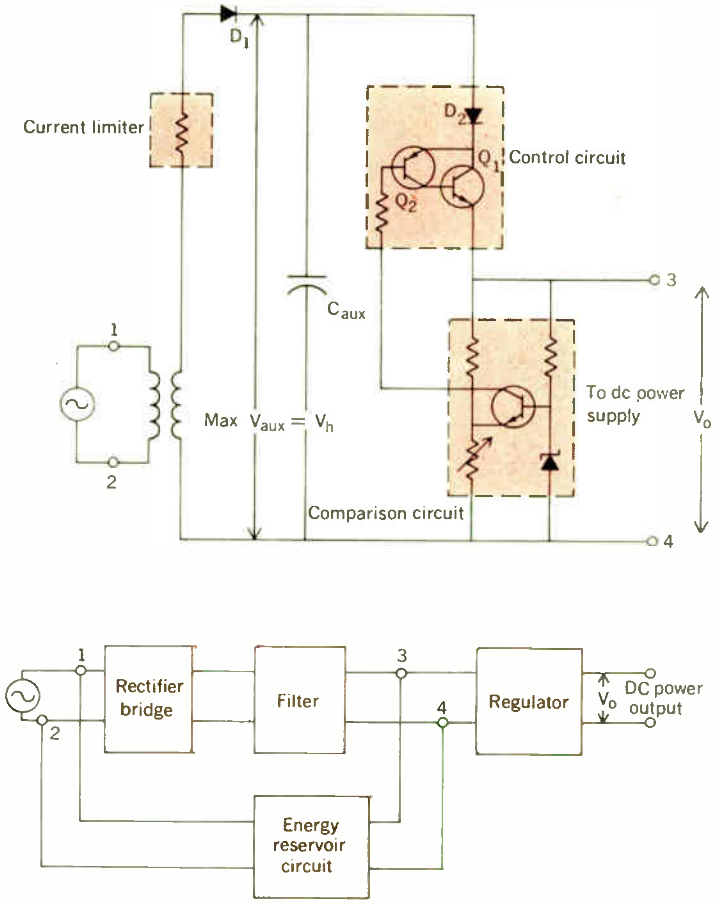


FIGURE 5. Energy-reservoir circuit and connection diagram to a dc power supply.



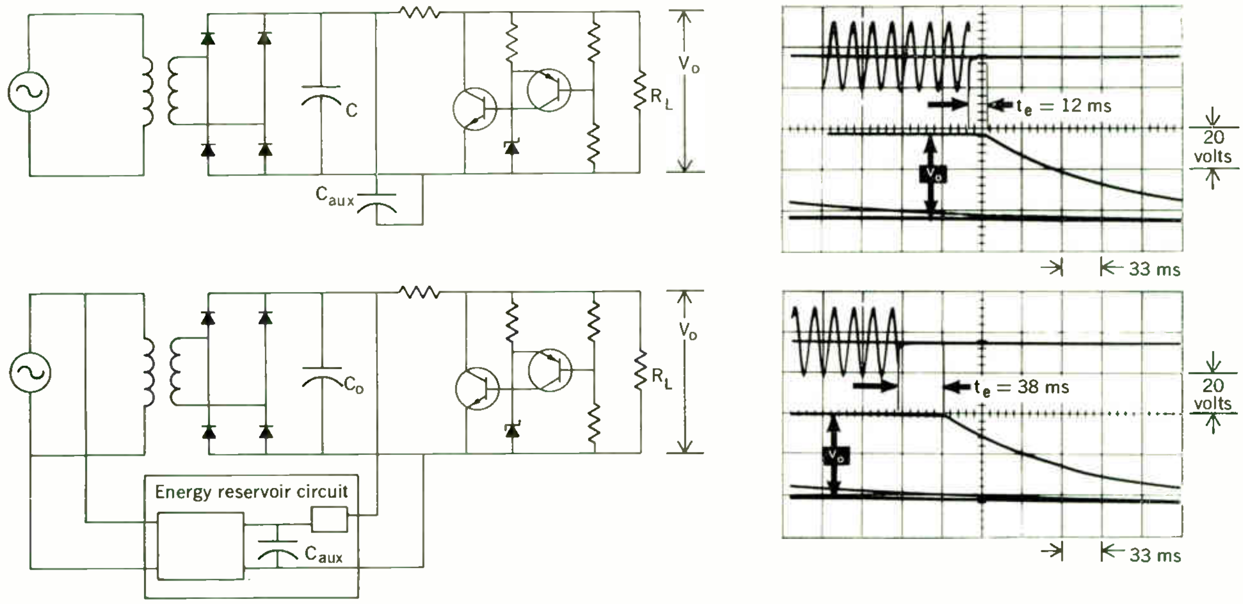


FIGURE 6. Comparison of two methods for extending t_e in a shunt-regulated, transistorized dc power supply. Top—Supplementing C with C_{aux}. Bottom—Supplementing C_o with C_{aux} in conjunction with an energy-reservoir circuit.

FIGURE 7. KPG-5 (T-1)/TSEC power supply.

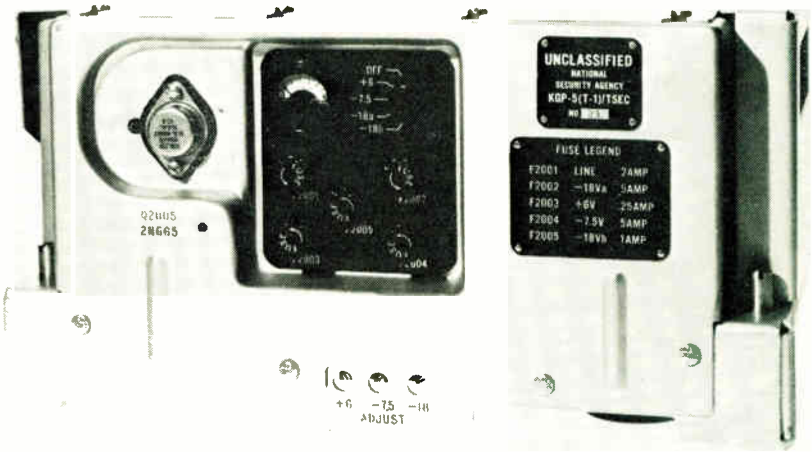
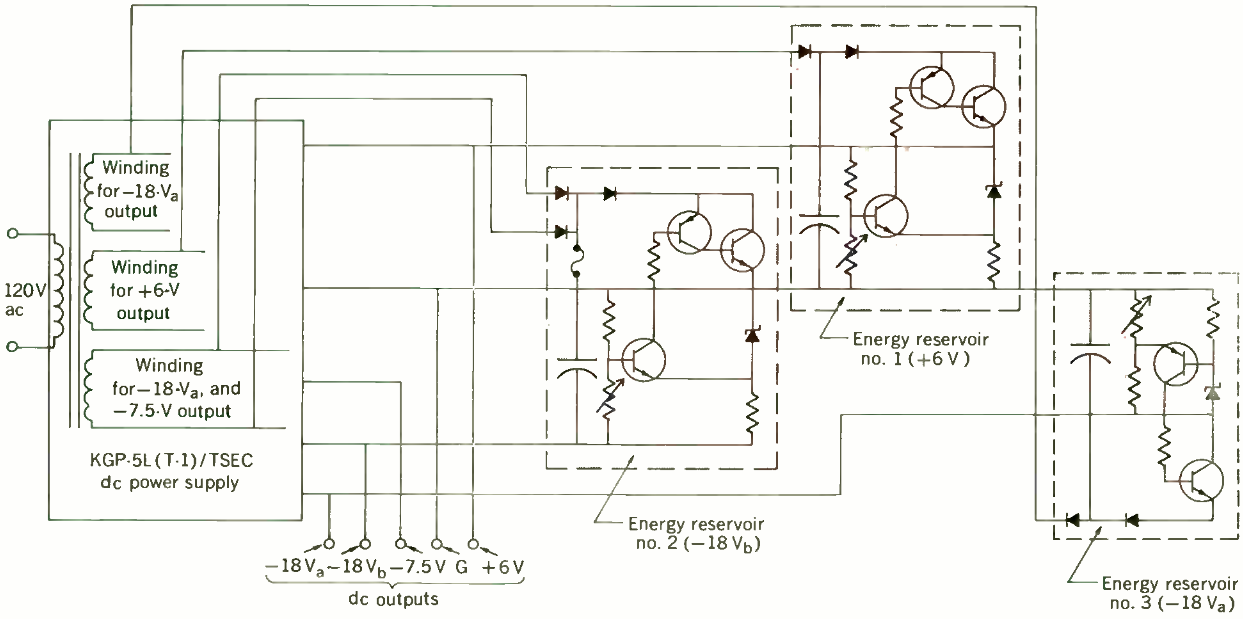


FIGURE 8. Energy-reservoir circuits of the KGP-5 (T-1)/TSEC dc power supply.



I. Data for selecting capacitors for energy-reservoir circuits

DC Output, volts	V_h, volts	V_h, volts	$V_h - V_r$, volts	I_{dc}, amperes	Calculated Capacitance, μF	Selected Capacitance, μF	Max. DC Voltage Rating, volts
6	19	6	13	0.5	3800	4000	25
−18 (b)	38	18	18	1	5550	5500	40
−18 (a) and −7.5	46	18	28	10	36 000	37 000	50

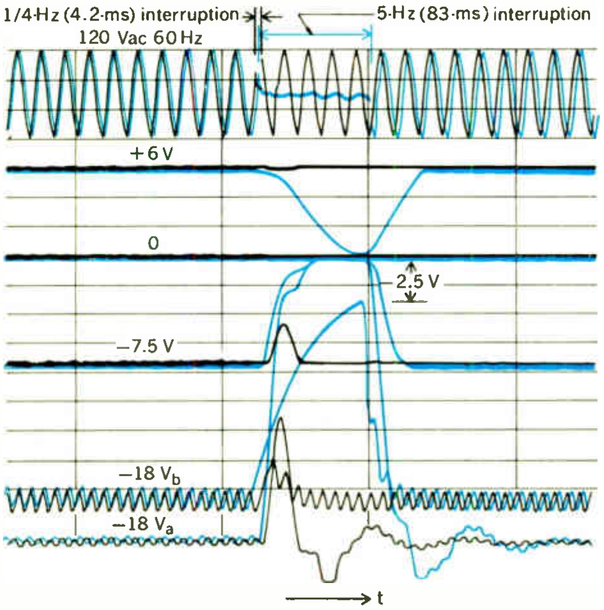


FIGURE 9. Oscillograph recordings of voltage outputs from the unit shown in Fig. 7 for a 4.2-ms interruption (black) and an 83-ms interruption (color).

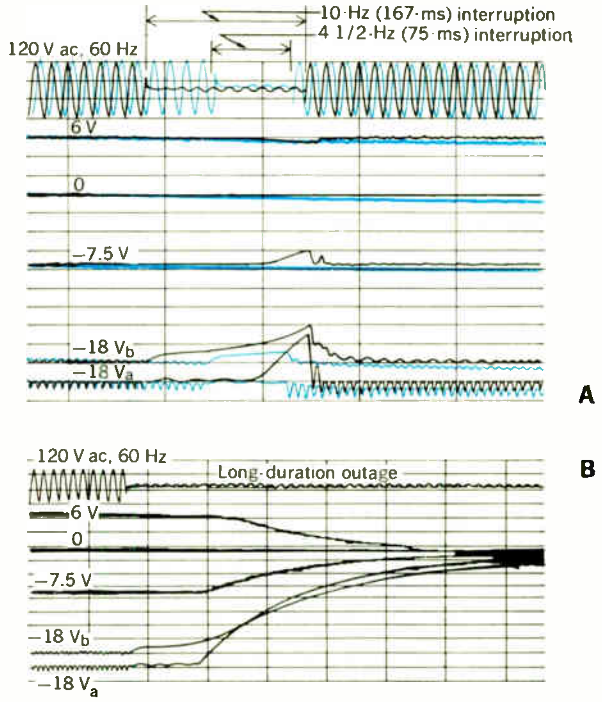


FIGURE 10. Oscillograph recording of output voltages from unit shown in Fig. 7 when (A) the ac line power is momentarily interrupted for 75 ms (color) and 167 ms (black) and (B) a complete ac power-line outage.

filter and a transistorized shunt regulator and is connected to the −18-volt(a) output. The total direct current is also 5 amperes.

Since the three dc outputs are derived from three separate secondaries of the input power-supply transformer, three individual energy-reservoir circuits are required. The dc power required by each energy-reservoir circuit can be driven from its respective secondary. Table I lists all data for the design of the circuit. The calculation of capacitances is based on 100-ms extended duration and neglects the value of t_{mi} in Eq. (4). Figure 8 shows the schematic diagram of the three energy reservoirs and the connections to the dc power supply.

Results

To prove the effectiveness of the energy-reservoir circuit, "before and after tests" were run with various momentary-outage durations. Figure 9 shows the performance of a KGP-5 (T-1)/TSEC power supply. Note that even a 4.2-ms interruption affects the −7.5-volt and −18-volt(a) output. With an 83-ms momentary interruption, all three outputs fall to zero volts except the −18-volt(b) output, which falls to approximately 14 percent of its rated value. Upon recovery of the ac voltage, note that the −18-volt(b) output exhibits overshoot and oscillations.

Figure 10 shows the performance of the KGP-5(T-1)/TSEC using the energy-reservoir circuit. With a 75-ms interruption, all the output voltages are essentially maintained; the overshoot of the −18-volt(a) output has been suppressed. Figure 10(A) also shows that with a 167-ms interruption all the outputs are essentially maintained with the −18-volt(a) output falling to 80 percent of its rated value; Fig. 10(B) shows a complete outage.

K. T. Huang received the B.S. degree in mechanical engineering from the Ordnance Engineering College in Taiwan in 1956. He subsequently continued his education in the United States, receiving the master's degree in electrical engineering from the University of South Carolina in 1956 and the Ph.D. from the University of Pittsburgh in 1967. He has since been employed with the Naval Civil Engineering Laboratory at Port Hueneme, Calif., as a research electrical engineer working on methods intended to provide noninterruptible electric power for naval use.

IEEE Reports for 1969

Introduction

J. V. N. Granger *President IEEE 1970*

Under the leadership of President Willenbrock, 1969 was a year of great beginnings for IEEE. "Operating in the adaptive mode" (to use Dr. Willenbrock's phrase), the Board of Directors and the various boards and committees reporting to it inaugurated a number of substantial changes in Institute structure that are certain to have far-reaching impact in the period ahead. In each instance, the proposals adopted were the result of a considerable effort of self-appraisal by the organization entities involved, or the result of investigation and analysis by *ad hoc* committees. Some of these programs were the culmination of efforts over a span of several years.

The most striking changes during 1969 were those directly affecting the makeup of the Board of Directors and the responsibilities undertaken by individual Directors. The Regional Activities Board, which came into being with Bylaw changes adopted in March 1969, is composed of the ten Regional Directors plus the Vice President elected by the membership, who serves as its Chairman. The RAB is responsible for the coordination, overall planning, and policy development in all matters arising from the geographical structure of IEEE. This board has set up a supporting-committee structure to facilitate its work. These committees, chaired in each case by a Regional Director or past Regional Director, cover all of the functions formerly assigned to the Sections Committee, plus several new functions that reflect the increasing importance of liaison between the various major boards and committees of the Institute, and of IEEE's financial planning.

The Technical Activities Board has been completely reorganized as a result of Bylaw changes adopted by the Board last November. It now consists of the Vice President, Technical Activities, as Chairman; a Vice Chairman; and six members of the Board of Directors, designated Technical Directors. Each Technical Director is specifically responsible for liaison with a particular Division (or "cluster") of IEEE Groups. The composition of these Divisions, which each include from one to seven of the present Groups, represents the result of detailed study by the 1969 TAB of the common interests and interrelationships of the present Groups. The basic purpose of the new organizational plan is twofold: first, to increase the breadth of representation of the Groups on the Board of Directors, and second, to provide an organizational mechanism for close coordination between Groups whose primary interests are closely related or whose activities follow a similar pattern. The new Bylaws that create these changes provide that Group members in each Division will elect the Technical Director who represents them every two years for a two-year term. To get the new structure under way, members of the current Board of Directors who were elected as Directors-at-Large have been appointed as Technical Directors. Their successors will be elected by the corresponding Division memberships.

In accordance with the Bylaws, the Awards Board undertook a complete review of the IEEE awards structure in 1969. The resulting recommendations have been received by the Board. Some have already been implemented; others are the subject of continuing study directed toward implementation.

The Publications Board carried forward its continuing study of ways and means to improve IEEE's primary publications and secondary information services. A number of changes were made in the format of IEEE SPECTRUM and of the STUDENT JOURNAL. All IEEE publications were offered for the first time, in 1969, in microfiche form.

The Educational Activities Board, under Prof. John Truxal, introduced a new series of tape cassette technological reports, and continued with the development of other experimental continuing education approaches introduced in 1968.

During 1969, an *ad hoc* committee chaired by E. W. Herold, Vice Chairman of TAB, undertook a study of the organization of the March Convention. In this effort, they had the assistance of Don Fink and, on a consulting basis, that of Don Larson, General Manager of WESCON. They also had the reports of a series of *ad hoc* studies conducted previously. Their recommendations to the Board were adopted at its January meeting. The new structure centers on a Conference Board, reporting to the Board of Directors and maintaining close liaison with TAB and RAB. Staff support comes from a newly created staff director, William J. Hilty, who will have in addition full responsibility for exhibit operations. The initial Conference Board, consisting of six IEEE members of outstanding stature and with wide experience in convention and exhibit matters, is already in place and at work on the 1971 event.

Ad hoc committees appointed by President Willenbrock made valuable specific recommendations in the areas of bringing younger engineers into active participation in the conduct of Institute affairs and in bringing the resources of the Institute to bear in developing opportunities for members of minority groups in the engineering profession. With special financial support for the necessary travel just made available by the Life Member Fund, three outstanding young members will participate as full members of the Long Range Planning Committee. That committee is giving particular attention to the question of the Institute's responsibilities and opportunities for service in the area of technology and public affairs.

A reading of the Treasurer's report will show that the IEEE, like all nonprofit institutions, and many that avow profit as an objective, suffered in 1969 from the inflationary rise in expenses and a weakening of some of its traditional sources of income. Under the leadership of Dr. Harold Chestnut, Treasurer during 1969, and his successor, Raymond Sears, the Finance Committee has expanded its organizational structure, and with the competent assistance of the Headquarters staff, has undertaken a detailed study of IEEE budgeting. The objective of this study is to increase the financial resources available to support new and important Institute programs by identifying and curtailing expenditures for activities that may have outlived their original importance or that might be amenable to new, and more economical, approaches.

I view 1970 as a year of consolidation for IEEE. We must give some of our new ventures an opportunity to mature. We must deal effectively with our worsening budget problems. We must reassure ourselves that what we are doing is the best response of which we are capable in living up to the definition of a profession set down by Martin Meyerson: "A profession is not only the trustee for a body of learning, it is a commitment to service."

Report of the Secretary—1969

Raymond W. Sears *Secretary IEEE 1969*

To the Board of Directors
The Institute of Electrical and Electronics Engineers, Inc.

Gentlemen:

The Report of the Secretary for the year 1969 is presented herewith.

The membership increased 2.5 percent during the year. The highest increase was in the Member grade, 3.8 percent. Senior Membership continues to show a gradual decline, 0.8 percent in 1969 and 5 percent over the past five years. Membership outside the United States and Canada increased 10 percent during 1969. New statistics in this Report indicate that 638 members are women.

There was a healthy growth of 8.5 percent in Group membership. Some 55 percent of the members above Student grade and 43 percent of the Student members participate in the Group program.

In 1969, 110 major conferences were sponsored or cosponsored by IEEE, 34 having exhibits, with paid registrations totaling 114 533, and additional exhibit attendances of 115 980. In addition, the 1969 International Convention attracted 60 543 attendees.

A total of 38 760 editorial pages were published in 1969, a slight decrease over the previous year. There were 184 Group Transactions published in 1969 with 20 266 editorial pages, as compared with 179 published in 1968 with 19 847 pages.

The technical activities of the Institute were reorganized through amendment of the Bylaws to provide for the clustering of Groups into six Technical Divisions, with members in the Divisions to nominate and elect an IEEE Director.

A new Conference Board, established in November, will have full responsibility for the operations of future IEEE International Conventions.

These data indicate a general growth trend and increased effectiveness in the organizational structure to better serve the membership.

Respectfully submitted,
Raymond W. Sears
Secretary

The manifold activities of the Institute are reported in detail for 1969 under four main categories: technical activities, publications and information services, educational activities, and board and standing committee activities. Among the highlights of the year were the following actions.

- Under the guidance of the Technical Activities Board, a fundamental reorganization into six Divisions comprising clusters of Groups, will permit election of Divisional Directors. These Directors will be voting members of a reconstituted Technical Activities Board.
- Both IEEE SPECTRUM and the STUDENT JOURNAL underwent changes both in direction and in editorial content with the aim of making them more relevant, significant, and interesting to their respective readers.
- Continuing education has taken the form of new tutorial seminars, management games seminars, and the introduction of an audio tape cassette service. Twenty-three new Student Branches were formed.
- The thrust of much committee work was toward future planning, taking into account the changing economic and social structure of the world, facilitating membership for those who are already members of comparable national societies, promoting membership

through better utilization of our own organizational units, and generally providing improved services to members.

Technical activities

Technical Activities Board. The seeds of reform, sown two years earlier, bore fruit by the end of 1969 with the reorganization of the support for IEEE's technical activities. The purposes of the rearrangement were to provide better mechanisms for responding promptly to changes in technology and for coping with the complex interdisciplinary problems that characterize the present era. The ability to take more timely and appropriate action will enable IEEE to give better service to individual members and to the profession they represent.

This is the second significant modification of the Group system since its establishment more than two decades ago, the first being the widespread incorporation of Technical Committees within individual Groups in the 1963–1964 era. The recent reorganization is more fundamental in nature. The Groups have now been clustered into six Divisions, each of whose composite memberships will nominate and elect an IEEE Director. The IEEE Vice President for Technical Activities will continue to be the Chairman of the Technical Activities Board and will speak for TAB's interest at the IEEE Executive Committee meetings. The TAB Vice Chairman—who will also be a Director—and the six Divisional Directors will join the TAB Chairman on the IEEE Board; they, plus the appointed chairman of the TAB Standing Committees, will constitute the voting members of the TAB Operating Committee. Suitable amendments have been made in the IEEE Bylaws to accomplish a smooth transition to the new organizational structure. *Ad hoc* committees were established in 1969 to tackle the details for making the reorganization work. Special attention was given to criterions on Group viability, which will serve as guidelines in the review of the total performance of each Group, to take place not less frequently than once each five years. An examination was made of the names or titles associated with Groups and Group officers and the internal and external significance of such proposed changes as "Group" to "Society" and "Chairman" to "President." Present member services were reviewed in relation to their interests and requirements, and relative to what other societies are doing.

The Group Divisions adopted at the conclusion of the 1969 reorganization are listed in the following. Their composition is not static. Every encouragement is offered for the migration of technical interests between Divisions, including the shifting or merger of Groups, whenever such adjustments will lead to beneficial long-term results.

Division 1

G-1 Audio and Electroacoustics
G-4 Circuit Theory
G-12 Information Theory
G-23 Automatic Control

Division 2

G-16 Computer

Division 3

G-2 Broadcasting
G-8 Broadcast and Television Receivers
G-10 Aerospace and Electronic Systems
G-19 Communication Technology
G-27 Electromagnetic Compatibility

Division 4

G-3 Antennas and Propagation
G-15 Electron Devices
G-17 Microwave Theory and Techniques
G-20 Sonics and Ultrasonics
G-21 Parts, Materials and Packaging
G-33 Magnetics

Division 5

G-5 Nuclear Science
G-6 Vehicular Technology
G-9 Instrumentation and Measurement
G-13 Industrial Electronics and Control Instrumentation
G-31 Power
G-32 Electrical Insulation
G-34 Industry and General Applications

Division 6

G-7 Reliability
G-18 Engineering Management
G-18 Engineering in Medicine and Biology
G-25 Education
G-26 Engineering Writing and Speech
G-28 Man–Machine Systems
G-29 Geoscience Electronics
G-35 Systems Science and Cybernetics

Some details of the reorganization were discussed in the December 1969 issue of SPECTRUM (pp. 122–124) and a further report is planned for a 1970 issue.

Standards. An *ad hoc* committee on IEEE's Standards Activities concluded that existing arrangements could not meet the basic requirement stated in the IEEE Bylaws, much less fulfill the expectations of IEEE members that were revealed as a by-product in a survey made two years earlier. Recognition of the Groups and their Technical Committees as the primary sources for IEEE Standards is evidenced by the *ad hoc* committee's recommendations that the Groups share more fully in all the steps in IEEE's Standards procedures. IEEE Standards will be published in the appropriate Transactions or Journals, with reprints available for additional individual sales. Other recommendations concerning Standards are expected to receive attention in 1970 from the IEEE Standards Committee, TAB, and the IEEE Executive Committee and Board.

Technical interest profiles. The concept of technical interest profiles for individual members was seriously proposed when plans were first made for the IEEE Headquarters computer. Progress in this direction has been speeded by reorganization and by joint effort of the Information Services Department and TAB.

Group membership lists indicate general technical interest for all IEEE members who belong to at least one Group, but about half of the IEEE membership was left undifferentiated. The response cards used for the 1970 IEEE directory permitted each member to identify individual technical interests in the subject list used jointly for indexing by IEEE and IEE (see details in the Information Services report). Concurrently, the Groups and their Technical Committees had been asked to describe themselves in terms of present activities and those projected to 1975, to review the joint IEEE/IEE subject list, and to suggest improvements. Membership response was good. Trial use of these data will be undertaken in 1970.

Finances. The TAB Finance Committee has continued its efforts to identify all items of income and expense related to technical activities. The interface between the Groups and TAB budgets and the total IEEE budget has received particular attention. To encourage long-range planning by each Group, efforts were made to describe each item of expense or income by means of simple formulas. Parameters derived from IEEE Headquarters operations—such as printing costs—are expected to change only slowly from year to year and may be forecast with sufficient accuracy to permit meaningful budgeting and financial planning. Other parameters controlled by activities and efforts of the individual Groups—for example, membership growth rates, the number of pages published per year, newsletters and other special publications, and conferences—may be similarly forecast by the Groups.

The details for the preparation of 1970 budgets were reduced to a computer program. Although most of this work was done outside, the program had been tested and proved to be compatible with the IEEE Headquarters computer. Efforts along these lines will continue, with the understanding that many Headquarters operating routines will be transferred to the computer early in 1970, thereby making feasible the preparation by computer of much of the material for financial statements and reports. Statistical studies are planned to show the current membership relations among the various Groups in a Division and between Divisions and, on a continuing basis, to reveal changes in membership patterns.

Technical planning. One purpose of the TAB reorganization was to become better prepared to recognize and respond to changes in electrotechnology. In some cases new technologies will emerge, but also, long-known technologies may come to the fore as elements in the solution of new and complex problems. The TAB Vice Chairman undertook major responsibility for these areas and established a Technical Planning Committee to assist with the work.

During 1969, an *ad hoc* committee study of IEEE's interests in manufacturing technology was completed. From an analysis of attendance records at special sessions sponsored at several conferences, it was found that most IEEE members interested in manufacturing technology are not members of any of the present Groups; the minority who belonged to Groups held memberships in about three quarters, which was an unanticipated diverse spread of interests. Recommendations of the *ad hoc* committee will be considered and acted upon in 1970.

A TAB Oceanography Coordinating Committee was established to bring together the interests of more than a dozen Groups in the ocean engineering field. The OCC is intended to provide a simple and flexible means for the IEEE Groups to interact with external organizations, such as the intersociety Offshore Technology Conference. The OCC also is responsible for a newsletter, available to any IEEE member on request, to report on present and planned activities of the Groups, acting individually and in concert. In the latter category is the first IEEE conference devoted solely to ocean engineering, which is cosponsored by the IEEE Panama City (Fla.) Section and the OCC and will be held in Panama City, September 21–24, 1970.

Late in 1969, an *ad hoc* committee was formed to explore IEEE's interests in electrography. This is illustrative of a change in emphasis or importance for a technology that has been with us for a number of years. To date, IEEE's treatment of the subject in publications and at conferences has been sporadic.

Convention technical program. In 1969, TAB continued its responsibilities for the technical program for the IEEE Convention. Particular attention was given by the Technical Program Committee to the technical content of the sessions planned for March 1970.

Of long-range significance was a TAB-initiated effort resulting in a special committee report to the IEEE Board, recommending establishment of a new IEEE Convention Board. This recommendation was adopted in the closing days of 1969. It is to be promptly implemented so the new Board shall have full authority and responsibility for the 1971 Convention. A new IEEE Headquarters staff organization is being established to support the Board and implement its decisions. The staff will have major operating responsibility for the IEEE Convention and Exhibition.

General activities. As in prior years, there is a continued growth in IEEE technical activities, as measured in terms of such parameters as published pages, conferences and symposiums held, Group Chapters, and Group memberships. All of these depend heavily on the leadership and efforts of individual IEEE members. The degree of our membership involvement appears to be a unique feature of IEEE's operations. The percentage of IEEE members who belong to at least one Group has increased (see Table I, page 56), continuing a trend of more than five years. The number of memberships per individual has declined slowly, but the total number of such memberships increased. The effect of a new fee arrangement for Student members of Groups (a fixed $2.00 fee for each Group membership, without limit as to number, replacing a $1.00 fee for a single Group membership plus full fees for any additional memberships) appears to have resulted in a significant increase in the total number of Student Group memberships but a decrease in the number of individuals holding these memberships.

Joint Technical Advisory Council. The JTAC, sponsored by the IEEE and the EIA (Electronic Industries Association), held six meetings during 1969. The Council has had four committees active in various areas of the radio art.

JTAC Committee 63.1—Electromagnetic Compatibility. This committee held three meetings during 1969 mainly devoted to exploring the efforts made by government and private concerns to adopt the recommendations made in the report "Spectrum Engineering—the Key to Progress." The JTAC's prime recommendation in this report was to establish a modern spectrum engineering and system-design philosophy for technical procedures relating to allocation and assignment of the radio spectrum. Adoption of such a philosophy would be essential in order to establish the "next-generation" spectrum engineering system.

To implement this recommendation, JTAC outlined a pilot project that would put the new frequency-selection concept into experimental operation in a trial region.

Results thus obtained from the project would then provide the basic information required to proceed further with the development of a flexible full-scale system. Many steps have been taken by numerous private and government entities to provide ultimately the much-needed data required to fulfill the JTAC recommendations.

The JTAC, together with a group from the committee, met with staff members from the Office of Science and Technology, the White House, and the Bureau of the Budget. At this meeting, it was suggested that the JTAC make similar presentations to appropriate committees of the House and the Senate.

JTAC Committee 65.1—Future Needs and Uses of the Spectrum. An attempt was made to conduct a new survey to update the 1968 report, "Future Needs and Uses of the Spectrum." Although additional technical answers are needed for a meaningful evaluation, a complete survey on the future needs of the spectrum cannot be reported without a full knowledge of the government needs as well. The Office of Telecommunications Management is proposing to establish a National Electromagnetic Compatibility Analysis Facility (NECAF). This is in response to the aforementioned JTAC reports to provide an entity for advance confidential review of prospective new developments to assure spectrum availability for those developments successfully completed. The JTAC is waiting to act further in this area after the establishment of NECAF.

JTAC Committee 66.2—Testing Sharing of TV Channels by LMRS. The JTAC established this committee to assist the FCC in tests being conducted by the Commission on the feasibility of the Land Mobile Radio Services sharing television channels. The tests have been completed and final acceptance of the FCC report by the Commissioners is awaited.

JTAC Committee 67.1—Spectrum Utilization Aspects in the Use of Space Techniques. This committee was established to study spectrum-utilization aspects of space techniques. It expects to release a report by November–December 1970, prior to the International Telecommunication Union's World Administrative Radio Conference on Space Telecommunications scheduled for 1971.

Publications and information services

During 1969, the Editorial Department processed 3480 papers and 1433 correspondence items for printing in IEEE publications, excluding the translated journals, giving a total output of 29 339 editorial pages. Of these, 24 075 pages were published in regular journals of the Institute, a slight increase over the previous year's output of 23 759 pages.

The practice of assessing voluntary page charges was adopted by the PROCEEDINGS OF THE IEEE and six Group Transactions and Journals, bringing to 12 the total number of Institute periodicals that follow this procedure. The percentage of authors' institutions honoring the voluntary payment, currently $50 per page, varied from one publication to another but averaged 55 percent overall.

The potential usefulness of microfiche as a publications medium was explored by conducting a test program in which the Transactions of three Groups were offered to members and subscribers in microfiche form, either instead of or in addition to the regular printed editions. A microfiche is a 105-mm by 148-mm transparency containing the images of up to 60 printed pages reduced in size by a factor of approximately 20. As a result of the test, it was decided to make all IEEE technical periodicals available in microfiche form in 1970.

Two significant improvements were made to the editorial communication channels. In the first of these, an ombudsman procedure was established to assist authors who have difficulty in communicating with, or receiving communications from, IEEE publication editors. Under the procedure, the Director of Editorial Services acts as a centrally located person to whom authors can turn for assistance. The second improvement was the inauguration of a monthly memorandum to all IEEE publication editors through which they are able to advise one another of their plans for future special issues, thus enabling potential conflicts to be avoided.

The Editorial Department was greatly saddened by two untimely deaths: Helene Frischauer, Administrative Editor of the Transactions and the PROCEEDINGS OF THE IEEE, and Seymour Tilson, Staff Writer for SPECTRUM.

IEEE Spectrum. Under the guidance of Editor J. J. G. McCue of M.I.T. Lincoln Laboratory, and with the approval of the IEEE Publications Board, several steps were taken to make SPECTRUM a more interesting, useful, and widely read publication. These included broadening the editorial coverage to include treatment of relevant social controversies, adopting a new cover and improved typography for some of the departments, and adding two new departments: "New Product Applications" and "News from Washington." That these measures were at least partially effective was readily evident from the major increase in reader mail received by the Editor and by a 42 percent increase in the number of letters to the Editor published.

Because of reader response to the broadened editorial coverage, the Publications Board developed a policy statement on the presentation of controversial social material in IEEE publications and at meetings, for the approval of the Board of Directors. A draft of the policy statement, published for comment by President Willenbrock in the Forum section of the September issue of SPECTRUM, elicited a membership response of two to one in favor of the policy of permitting the inclusion of relevant social material in IEEE publications and meetings. (The final wording of the statement was published in SPECTRUM, March 1970, page 6, following approval by the Board of Directors in January 1970.)

A total of 85 articles and 94 letters were published during the year, as compared with 82 articles and 66 letters the prior year. Nine articles were written by editorial staff members. The total pages published in SPECTRUM numbered 1884, of which 1279 were devoted to technical and editorial material and 605 to advertising and related material.

Proceedings of the IEEE. An important event in the PROCEEDINGS year was the appointment of a new Editor, David Slepian of Bell Telephone Laboratories. He took over from M. E. Van Valkenburg, who had provided valuable editorial guidance to the PROCEEDINGS for three years. The members of the PROCEEDINGS Editorial Board actively assisted Dr. Slepian throughout the year with the review of papers and with plans for invited papers and special issues.

Four highly successful special issues, each devoted to a single area of major interest, were published in 1969. The subjects covered were remote environmental sensing (April), topside sounding and the ionosphere (June), materials and processes in integrated electronics (September), and technology and health services (November).

The program of inviting technical leaders to write tutorial review papers in their areas of special competence was continued. Eleven of these invited papers were published during the year on subjects ranging from glass lasers to the control of electric utilities. The year saw the appearance of 2416 pages in the PROCEEDINGS, of which 2254 were editorial pages and the remainder contained paid advertising and related material. The total number of papers published was 171, of which 132 appeared in special issues. The technical letters section contained 570 pages devoted to the publication of 456 letters.

Group Transactions and Journals. The technical publications of the Groups again encompassed a major fraction of the IEEE publication output. During the year 184 issues constituting 20 266 pages were published, a slight increase over the 19 847 pages published the year before.

The number of Transactions published remained at 31 and the number of Journals at two. Of these 33 publications, five were issued monthly, eight bimonthly, 16 quarterly, and four aperiodically.

The current program of evaluating Group publications, set up by the Publications Board and TAB OpCom in 1968, was concluded during the year by 17 three-man task forces. It is expected that the task force reports and recommendations will be extremely helpful to the Groups in strengthening their publications. The TAB Publications Committee focused its attention particularly on the factors that contribute to delays in the publications and distribution of our periodicals. Perhaps to the surprise of many Group officers, the procedures and practices employed by a considerable number of Group Editors have been responsible for a great deal of the systematic delays, as distinguished from delays caused by external, more random events, including strikes. Once the nature of the problems was understood, remedial action could be initiated through the joint efforts of the Editors, the IEEE staff, and the publishers; there do not appear to be immediate prospects of a speedup in the U.S. postal system, which introduces a variable delay in the final step of the publication and distribution cycle.

For the second year in a row, one of the Institute's three printers suffered a strike, thus seriously aggravating a continuing problem of meeting production schedules. The services of three additional technical typesetters were acquired during the year, two in England and one in the U.S., and by the year's end significant improvement was beginning to be made in meeting schedules.

The Editorial Department staff was strengthened by the appointment of H. James Carter as Managing Editor of the Transactions, to assume responsibility for the production of all Group Transactions and Journals.

IEEE Student Journal. Professor Frank S. Barnes of the University of Colorado continued to implement the editorial innovations he introduced in 1968, when he was appointed Editor of the STUDENT JOURNAL. Each of the five issues published in 1969 was organized around a specific theme—graduate education, electronic communication, case histories of achievement, social issues and survival, and instrumentation. Under the leadership of Professor Barnes and an Editorial Board of prominent engineers, the STUDENT JOURNAL continued to take on a new look, with livelier graphics and thematic art. With the appointment of four students to the Editorial Board in the spring of 1969, readers gained a direct representative voice in tailoring the magazine to their tastes. C. W. Beardsley was named Managing Editor, succeeding A. A. McKenzie, who continued his affiliation with the STUDENT JOURNAL as Editorial Consultant.

As in previous years, an additional 20 000 copies of the September issue were sent to Branch Counselors for distribution to potential Student members. Since 1967 Student members have been given the option of receiving either the STUDENT JOURNAL or SPECTRUM as part of their dues. In 1969, 51 percent of the new students and 45 percent of the renewing students chose the STUDENT JOURNAL instead of SPECTRUM.

During the year, 53 signed articles and five guest editorials, as well as other technical and career information, appeared in the 276 pages of this publication. A correspondence column, which initially contained five letters, was inaugurated in the November issue.

Translated Journals. The Institute continued sponsorship of the program for translating and publishing papers from two Japanese, one Ukrainian, one Chinese, and four Russian technical journals. The journals translated from Russian were published by IEEE's former contractor; the balance were published by IEEE with the aid of grants from the National Science Foundation. In 1969, more than 9000 English pages were published in this translation program, of which 4853 were from Russian, 3607 from Japanese, 449 from Ukrainian, and 512 from Chinese.

Advance tables of contents of issues to be translated were carried each month in SPECTRUM, as were signed critical reviews of selected papers that had been published in English.

More than 1600 articles, brief communications, letters, and other items were published in English during 1969, of which 1173 were full technical papers.

Regional, Section, and special publications. Two Regional publications, inaugurated in 1967, continued publication in 1969. Four issues of IEEE ELECTROLATINA were published and distributed to the approximately 2000 members in Region 9 (Latin America). This technical publication contains articles and other material in Spanish and Portuguese. Region 8, serving nearly 5000 members in Europe, published the IEEE REGION 8 NEWSLETTER four times during the year.

A major activity of many Sections is the publication of a monthly Bulletin for the announcement of local activities. Sixty-nine IEEE Sections are now issuing monthly publications.

Electrical Engineering. This IEEE managment newsletter of six to eight pages, first issued as such in 1964, notes completed and impending changes in the structure, Bylaws, policies, and operations of the Institute and the evolution of its organization units.

Information services. Data-base use and development were the central activities of the Information Services Department during 1969. Production capability of the database system established during 1968 was refined this year to allow on-schedule delivery of year-end indexes to IEEE technical journals.

System planning for direct on-line access to the data base began this year, as did development of capabilities to produce computer tapes for public distribution and to make selected abstracts available for publication in IEEE Transactions.

The first computer tapes containing abstracts and related bibliographic information were delivered to us by the Institution of Electrical Engineers (London) under a new agreement that continues joint IEEE–IEE publication of *Electrical and Electronics Abstracts*, *Computer and Control Abstracts*, and the associated *Current Papers* journals.

The technical-subject-classification scheme developed in 1968 with the IEE was used during 1969 in an expanding program of author-assisted indexing. Also based on this scheme, technical-subject-interest profiles of over 85 000 IEEE members were collected and stored on the IEEE computer for use and analysis. In addition, this scheme was used by TAB to compile technical profiles of the IEEE Groups.

Author-selected citations were collected, as a first step toward a network of meaningful linkages between technical papers in the data base.

National Science Foundation support received for Information Services developmental work amounted to more than $70 000 for 1969–1970, and a proposal for increased NSF support for a three-year development and operating program has been submitted.

Advertising. During the year, Sweatman & Fordham was appointed to represent IEEE publications and the International Convention and Exhibition among advertisers and exhibitors in Great Britain and Europe. Another addition was Hendrik V. Prins as Manager, Marketing Services. Mr. Prins has the overall responsibility for IEEE advertising and marketing research including a newly created marketing and research program, "Synoptic Marketing." This service, which will be offered by the IEEE Advertising Department early in 1970, will make available in-depth information about the overall membership of the IEEE.

In 1969, industry-wide IEEE Advertising Awards were established to recognize annually the important contribution that advertising makes to the industry and to the profession through dissemination of technical information.

Educational activities

The Educational Activities Board, under the chairmanship of Dr. John G. Truxal, Polytechnic Institute of Brooklyn, held five meetings during 1969 at which it reviewed the activities of its standing committees and initiated actions.

Accreditation. The chairman of the Accreditation Committee is Dr. H. W. Farris, University of Michigan, who, with his committee, maintains continual liaison with ECPD and IEEE representatives in evaluating criterions and curriculums at universities in the United States.

I. IEEE Group Membership, December 31, 1969; two-year comparison

Group No.	Group Name	Students	Members	1969 Total	1968 Total
1	Audio and Electroacoustics	1 001	4 074	5 075	4 572
2	Broadcasting	317	1 773	2 090	2 009
3	Antennas and Propagation	890	4 313	5 203	4 937
4	Circuit Theory	2 967	7 200	10 167	8 868
5	Nuclear Science	459	2 051	2 510	2 453
6	Vehicular Technology	202	2 157	2 359	2 192
7	Reliability	97	2 541	2 638	2 486
8	Broadcast and Television Receivers	359	2 071	2 430	2 229
9	Instrumentation and Measurements	494	4 354	4 848	4 732
10	Aerospace and Electronic Systems	1 114	7 978	9 092	9 150
12	Information Theory	909	4 300	5 209	4 558
13	Industrial Electronics and Control Instrumentation	391	3 082	3 473	3 293
14	Engineering Management	754	5 971	6 725	6 293
15	Electron Devices	3 209	6 750	9 959	9 175
16	Computer	4 200	12 662	16 862	14 982
17	Microwave Theory and Techniques	1 139	5 781	6 920	6 370
18	Engineering in Medicine and Biology	1 311	3 895	5 206	4 614
19	Communication Technology	1 661	7 970	9 631	8 972
20	Sonics and Ultrasonics	106	1 251	1 357	1 246
21	Parts, Materials and Packaging	40	2 068	2 108	2 176
23	Automatic Control	1 987	5 438	7 425	6 769
25	Education	190	1 776	1 966	1 880
26	Engineering Writing and Speech	254	1 948	2 202	2 103
27	Electromagnetic Compatibility	66	1 811	1 877	1 719
28	Man-Machine Systems	222	1 241	1 463	1 225
29	Geoscience Electronics	249	1 458	1 707	1 571
31	Power	1 453	12 420	13 873	12 897
32	Electrical Insulation	44	1 202	1 246	1 139
33	Magnetics	183	1 951	2 134	2 019
34	Industry and General Applications	394	4 893	5 287	4 713
35	Systems Science and Cybernetics	1 093	3 669	4 762	3 987
		27 755	130 049	157 804	145 399

Continuing education. Among the continuing programs of the Board are the updating of university short-course listings published in SPECTRUM, additions to the slide-tape lecture series for use of IEEE entities, and updating and reissuance of a manual of services and material available in the continuing education area.

Two short courses were presented during the year with enthusiastic response from the membership. Three tutorial seminars were presented at the 1969 International Convention.

Management Games Seminar, the first of a series of home-study courses, has been presented twice during the past year with an enrollment of over 3500 students. The course will be presented again in 1970 to the membership in Regions 1 through 7. Facilities are being arranged to test a "Dial Access" information system. This will be in the form of 5–8-minute, current-status-of-technology reviews prepared by eminent Group members, which can be heard by telephone. IPL '69, an audio-tape cassette recording of a Workshop on Industrial Processing Languages, inaugurated a new service entitled Cassette Colloquia through which the Educational Activities Board hopes to provide technical information and a record of workshops, seminars, and conferences.

Precollege guidance. Three meetings have been held under the chairmanship of Dr. Lindon E. Saline, General Electric Company. Subcommittees to coordinate guidance activities in the following specific areas have been established:

1. Coordination with ECPD and its constituent societies to launch a nationwide, profession-wide guidance program.
2. New inexpensive guidance brochures are being developed.
3. Guidelines are being promulgated for coordination of guidance activities at the local level.
4. A prospectus is being developed for the production of a guidance film on "Engineering Technology."
5. A study was initiated under the direction of Dr. Donald Super, Columbia University, to determine which factors have what degree of influence on a youngster's career determination—how high school students get "turned on" or "turned off" in the selection of engineering as a future career.

Student activities. The committee, chaired by Dr. Richard B. Russ, Union College, held two meetings in 1969. The annual Vincent Bendix Award program was administered with grants to seven Student Branches totaling $2605.

The committee has reviewed and evaluated in depth the IEEE Prize Paper structure and has made recommendations for consideration by other boards and committees of the Institute. IEEE's role in student activities was reviewed and the following reasons for student membership in the IEEE were developed:

1. To establish a base for further Institute membership.
2. To serve and augment school programs.
3. To promote leadership training.
4. To give vocational orientation as a stimulation for further motivation.
5. To identify the electrical engineering profession with the student and the school by establishing avenues of communications.

An *ad hoc* committee was appointed to review existing procedures and recommend necessary changes in criterions for IEEE Student/Student Associate Branches and membership.

IEEE Student and Student Associate Branches enjoyed a growth of 23 new Branches, making a total of 342.

Board and standing committee activities

Admission and Advancement Committee. During the year 30 805 membership applications for admission and transfer were processed. This compares with 30 400 processed in 1968. Some 1561 required review by the Admission and Advancement Committee during the 12 meetings held in 1969, when actions were taken as follows:

	Senior Member	Member
Admissions approved	307	583
Admissions rejected	49	36
Transfers approved	437	99
Transfers rejected	41	9
	834	727

Membership by grade and percentage is shown in the two-year comparison below:

	Dec. 31, 1969		Dec. 31, 1968	
Grade	Number	Percent of Total	Number	Percent of Total
Honorary	4		4	
Fellow	2 917	2	2 885	2
Senior Member	24 815	15	25 023	15
Member	101 058	61	97 326	60
Associate	13 235	8	13 200	8
Student	24 319	14	23 930	15
	166 348	100	162 368	100

Awards Board. During 1969 the Awards Board conducted an extensive study of the IEEE awards. Final recommendations will be submitted to the Board of Directors early in 1970.

The Awards Board considered and approved for submission to the Board of Directors for final approval the recommendations of its committees for candidates for five Major, eight Field, three Prize Paper, and two Scholarship Awards.

The Awards Board approved recommendations for replacement of several IEEE Representatives whose term of membership expired on three Intersociety Boards of Awards.

Fellow Committee. The committee reviewed 395 nominations for Fellow grade. The committee submitted to the Board of Directors the names of 123 candidates, with accompanying citations, recommended for elevation to Fellow grade as of January 1, 1970.

Finance Committee. The committee held seven meetings in 1969 and primarily concerned itself with the review of the investments of the Institute, the creation of the Investment Committee, the comparison of actual results this year against the approved budget, the analysis of additional space needs, the determination of what expenses could be reduced and income augmented in this and future years, and the preparation of the 1970 budget.

During the year, in which the overall securities market sustained a substantial loss in value, the committee reviewed the investments with its appointed counselor. An Investment Committee, composed of representatives from the Board of Directors along with some outside experts, has been created and has met with the investment counselor, and is preparing its charter.

An analysis of the operating functions and the cost of performing various individual services for the members was started during 1969. This indicated several areas where the cost of services being performed should be repriced or the work force realigned to balance the work being performed, the income generated, and the funds available to support the particular function.

History Committee. The preparation of a history of the formation of the IEEE from the merger of the American Institute of Electrical Engineers and the Institute of Radio Engineers is an ongoing project of Nelson Hibshman, retired IEEE Executive Consultant, under the auspices of the History Committee. A first step was taken in 1969 for assembling a limited collection of archival documents having special relevance to the Institute. The committee was saddened by the death in August of Haraden Pratt, its Chairman since the formation of the IEEE in 1963.

Internal Communications Committee. The committee has operated as a far-ranging advisory group and has constantly reviewed internal communication problems and recommended ways to improve the interface between the Institute and the member.

The committee generated a program for officer recognition by the preparation of special tiepin/clips with the Institute emblem and identifying color borders—rust for Group Chairman, turquoise for Section Chairman, and royal blue for Life Member. It also developed recognition insignia for Past Presidents and Past Directors of the Institute. In addition, a fresh new family of certificates was developed and their use begun.

In support of the need of the Membership and Transfers Committee, the ICC has been asked by the Executive Committee to expand membership promotional programs that are needed further to enhance the Institute entity to both recruit members and retain those whose job function or interest might have changed.

The Intersociety Relations Committee. In conjunction with designated boards and standing committees, the ISRC compiled a comprehensive status report of activities. The report resulted from the responses obtained from 158 representatives to 32 societies located throughout the world. The responsibility for appointments to outside organizations for which the Professional Relations Committee had been responsible was delegated to the Educational Activities Board. The appointments so delegated were to the NCEE and the Ethics Committee and Young Engineers Committee of ECPD.

The ISRC focused a good part of its time on the ISRC Subcommittee on Scientific and Cultural Exchanges and its effort to enlarge the scope of the scientific and cultural exchange to include other Eastern European nations.

The 1969 IEEE/Popov Exchange was the most successful to date from the point of view of numbers of participants and the quality of the installations visited.

Life Member Fund Committee. At the annual meeting of the committee, the criterions for supporting the travel expenses of individuals who represented IEEE at meetings for the determination of international standards were discussed. The funds would be granted to those individuals who could not readily obtain alternate sources since these funds are to supplement rather than replace presently available funds.

The committee, at the request of Haraden Pratt, Chairman of the History Committee, agreed to make available the sum of $2500 for the purchase of display equipment to house objects and papers of historical significance.

Long Range Planning Committee. The committee envisions its function as that of a coordinator, with its work done through the cooperation and efforts of subcommittees assigned to study specific tasks and/or by standing subcommittees representing continuing activities of the Institute. It should attempt to bring the human factors into the thinking-oriented engineer's life. In conjunction with other engineering societies, IEEE should take the initiative to convince its members to contribute their intellectual abilities toward solving society's problems.

The committee recommended that a study be performed by representatives of the Regional Activities Board to determine the desirability of reducing dues for those members who reside outside the United States of America and are members of national societies.

It was recommended that the Institute develop an operating reserve, by the end of 1976, of $7 200 000 to cover years in which the Institute might operate at a loss and not desire temporarily to cut back services rendered to members.

Membership and Transfers Committee. All members of the committee were designated "Area Representatives" and assigned to particular IEEE Sections with which they maintained regular communication in the matter of membership and transfers activities.

The committee was authorized to publish in the April 1969 issue of SPECTRUM an article on "Operation GIT," the continuing drive with the objective of realizing an annual 10 percent increase in membership. Included was a postcard on which members of the Institute could furnish the names and addresses of prospective members. IEEE membership promotional material was furnished to 843 potential members as a result of this promotional effort.

During the year, IEEE staff members operated Membership Service Desks at 16 major IEEE Conferences.

Nominations and Appointments Committee. Reports were submitted to the Board of Directors recommending candidates for election by the annual Assembly and by the voting membership and appointment to committees and boards. It reported to the Executive Committee, recommending candidates to serve on those committees reporting to it.

Regional Activities Board. In March 1969 the Sections Committee was abolished and a new Regional Activities Board (RAB) established to assume the responsibilities of the Sections Committee and to give full attention to the important geographical activities of the Institute. The Board of Directors approved a new Bylaw (308) defining the composition and scope of activities of RAB. Upon the recommendation of RAB, the Board of Directors approved a new border for Region 8 to achieve a clear delineation of its southern boundary, together with a minor adjustment to include the Middle East. The country of Greenland was simultaneously assigned to the territory of the Denmark Section in Region 8. The Directors likewise abolished the Constitution for Sections and incorporated Articles of that Constitution into the IEEE Bylaws.

RAB approved a new document, "Section Student Activities Manual," which provides suggested guidelines for the important relations between Students and the Sections.

The Board of Directors approved, on the recommendation of RAB, the following statement:

"When the IEEE, or any of its organizational elements, engages in an activity which is specifically national in character, that is to say, an activity which by its nature reflects an intrinsic relationship to a specific national environment, the guiding policy should be that undertaking such an activity should not preclude IEEE action on the corresponding problem in any other national environment. It should be noted that this policy contemplates the possibility that the IEEE might adopt differing positions relative to a particular problem area, in its different national environments."

The following RAB proposal was approved by the Board of Directors and the necessary Bylaw revisions adopted for implementation:

"It is proposed that the Board of Directors authorize the Executive Committee to extend membership privileges, on a reciprocal basis, to members in good standing of those National Societies in our field of interest which wish to enter into such a relationship. In this context, an exchange membership implies collection of the same dues and Group fees as for regular membership; full membership privileges in every respect excepting the right to vote in the election of officers and directors; and automatic acceptance of applications for exchange membership status which carry a certification by an officer of the National Society involved attesting to the applicant's membership status in that Society, without entrance fee. Exchange membership privileges would be limited to a maximum of three years for any individual."

Report of the Treasurer—1969

Raymond W. Sears *Treasurer IEEE 1970*

The financial activities of the IEEE, for the year ending December 31, 1969, are reported on the following pages, on a consolidated basis for the first time by the inclusion of all Group operations. Financial results for Group operations, the Investment Fund, and the IEEE General Account are shown individually with the appropriate separation of interaccount transactions, so the consolidated summation is indicative of overall Institute operations.

From an overall standpoint, the Institute had a financially troublesome year. Whereas results from regular operations show a net surplus of $196 939, realized losses of our investment fund from sales of securities amounted to $254 993, thus reducing the surplus to an overall loss or reduction of our Operating Fund balance of $58 054. In addition to the realized loss in our securities transactions, the unrealized reduction in market value of our securities totaled $657 987. Steps already have been taken by the Finance and Executive Committees aimed at obtaining a better market position and performance during 1970.

The General Account includes income and expenses related to general membership activities, publication of the PROCEEDINGS, SPECTRUM, and the STUDENT JOURNAL, advertising, Information Services, International Convention, and other services for all members. It is interesting to note that membership fees constitute the largest portion (50 percent) of the General Fund income. The Group Account includes publications, conferences, and all activities administered by the Groups and the Technical Activities Board. The Investment Account records the results of the year's operation of our investment activities, including dividend and interest income and capital gains or losses.

The General Account, after appropriate transfers, showed a net loss of $106 501 for 1969 in contrast to a net gain of $283 400 for 1968 on a directly comparable basis. Our difficulties in meeting our budget expectations this year resulted from a number of factors. We installed a new and more efficient computer designed to increase the capabilities for meeting the needs and requirements of IEEE's operating units. Nonrecurring costs of computer rental for testing the new system, as well as a three-shift, seven-day operation for six months, was one of the major causes for the computer budget overrun. In addition, we invested further in the development of our Information Services Program aimed toward both technical and financial advantages in the future. Finally, advertising fell off, we had difficulties owing to a printer's strike, and we began to feel the increased cost of printing. Printing costs are escalating at a rapid pace and will be severely felt in 1970.

The surplus from Group Operations is due mainly to a nonrecurring transfer of accumulated assets from Joint Meeting Accounts to Group Accounts.

In summary, although we experienced a modest 2 percent growth in Institute and Group memberships, we encountered financial difficulties because of inflation, extraordinary expenses relating to the computer installation, and continued investment in expanding member services. New procedures have been instituted aimed at a better control of expenditures in the various operating departments of IEEE to attain better budget compliance and to keep expenditures in line with income in 1970.

Auditors' report

Price Waterhouse & Co.

60 Broad Street
New York 10004
March 18, 1970

To the Board of Directors of The Institute of Electrical and Electronics Engineers (Incorporated)

We have examined the statement of financial position of The Institute of Electrical and Electronics Engineers (Incorporated) as of December 31, 1969 and the related statement of income and operating fund balance for the year. Our examination was made in accordance with generally accepted auditing standards and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

As more fully explained in Note 2 to the financial statements, the accounts of the Institute include for the first time in 1969 the income and expense of the Institute's Groups. As a result of this change in accounting, which we approve, the excess of total expense over income for the year has been reduced by $353,440.

In our opinion, the accompanying financial statements examined by us present fairly the financial position of The Institute of Electrical and Electronics Engineers (Incorporated) at December 31, 1969 and the results of its operations for the year, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

Price Waterhouse & Co.

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (INCORPORATED)
STATEMENT OF INCOME AND OPERATING FUND BALANCE
DECEMBER 31, 1969

(Note 2)

	General Account	Groups	Investments	Total
Operating income:				
Membership, entrance fees and dues	$3,241,813	$670,423		$3,912,236
Advertising	710,102			710,102
Periodicals subscriptions, publications and sales items	667,988	1,075,077		1,743,065
Information services and products	255,984			255,984
Conventions and conferences	1,249,977	806,659		2,056,636
Investment income	116,488		$153,552	270,040
Miscellaneous other	243,822	257,197		501,019
Total	6,486,174	2,809,356	153,552	9,449,082
Operating expenses:				
Headquarters services to members	1,078,634	190,275		1,268,909
Support of regions, sections and branches	534,897			534,897
Periodicals publications and sales items	2,038,566	2,256,118		4,294,684
Information services	351,196			351,196
Conventions and conferences	950,735	733,985		1,684,720
General administration	1,064,682	30,826	22,229	1,117,737
Total	6,018,710	3,211,204	22,229	9,252,143
Excess of operating income over (under) operating expenses (Note 3)	467,464	(401,848)	131,323	196,939
Loss on sale of securities			(254,993)	(254,993)
Excess of income over (under) expenses for the year	467,464	(401,848)	(123,670)	(58,054)
Add (*subtract*)—Intrafund transfers:				
Investment income to general account	131,323		(131,323)	
Support of groups from general account	(755,288)	755,288		
Portion of accumulated capital gains from investments to general account	50,000		(50,000)	
	(106,501)	353,440	(304,993)	(58,054)
Fund balance, beginning of year (Note 2)	3,216,861	569,200	684,969	4,471,030
Fund balance, end of year	$3,110,360	$922,640	$379,976	$4,412,976

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (INCORPORATED)
STATEMENT OF FINANCIAL POSITION
DECEMBER 31, 1969

(Notes 1 and 2)

Operating Fund

Current assets:		
Cash including $1,314,000 in federal funds, commercial paper and a savings account	$1,793,178	
Marketable securities, at cost, approximate market value (Note 4)—$5,085,000	4,986,029	
Notes and accounts receivable, less allowance for doubtful accounts of $24,563	509,760	
Prepaid expenses, inventory, etc.	515,917	
Total current assets		$7,804,884
Fixed assets:		
Office equipment and leasehold improvements, at cost, less accumulated depreciation and amortization of $497,756		366,969
Total assets		8,171,853
Less—Current liabilities:		
Accounts and accrued expenses payable	407,447	
Deposits by sections and other custody accounts (Note 4)	251,885	
		659,332
Deferred income:		
Groups	589,776	
Dues	1,593,682	
Subscriptions	298,481	
Convention	617,606	
		3,099,545
Total current liabilities		3,758,877
Operating Fund balance (accompanying statement)		4,412,976

Property Fund

Advance to United Engineering Trustees, Inc. (Note 5)		265,000

Restricted Funds

Cash	74,262	
Marketable securities, at cost, approximate market value $261,000	264,467	
Restricted Funds balance (accompanying statement)		338,729
Total all funds		$5,016,705

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (INCORPORATED)
STATEMENT OF CHANGES IN RESTRICTED FUNDS
FOR THE YEAR ENDED DECEMBER 31, 1969

Restricted Fund	Fund balance January 1, 1969	Receipts from contributions and marketable securities	Disbursements for awards and related costs	Fund balance December 31, 1969
Life Member Fund	$100,182	$5,914	$16,546	$89,550
International Electrical Congress—St. Louis Library Fund	6,913	204	200	6,917
Edison Medal Fund	17,358	1,386	1,016	17,728
Edison Endowment Fund	7,986	263	263	7,986
Lamme Medal Fund	9,428	259	370	9,317
Mailloux Fund	1,060	41	44	1,057
Volta Memorial Fund	13,632	503	1,985	12,150
Kettering Award Fund	2,685	153		2,838
Browder J. Thompson Memorial Prize Award Fund	5,266	143		5,409
Harry Diamond Memorial Prize Award Fund	1,022	44	5	1,061
Vladimir K. Zworykin Television Award Fund	3,506	88	506	3,088
W. R. G. Baker Award Fund	9,839	405		10,244
William J. Morlock Award Fund	5,456	207	300	5,363
W. W. McDowell Award Fund	9,533	350	737	9,146
William D. George Memorial Fund	855	22	150	727
Frank A. Cowan Award Fund	147,379	6,614		153,993
IEEE Region 9 Award in Electric Power Engineering Fund	2,071	84		2,155
Total	$344,171	$16,680	$22,122	$338,729

NOTES TO FINANCIAL STATEMENTS—DECEMBER 31, 1969

NOTE 1—THE INSTITUTE: The Institute is a scientific and educational organization organized for the advancement of the theory and practice of electrical and electronics engineering and related arts and sciences primarily through Sections and Groups. Sections are unincorporated geographical subdivisions of IEEE. The books and records of the Sections are maintained by the treasurers of each Section and are not included in the accompanying financial statements. Groups are unincorporated units within IEEE formed to serve the specialized professional interests of members and to coordinate these with the local activities of the Sections and the broader activities of the Institute. The Groups promote the technical interests of its members through symposia, conferences and various publications. The Groups receive income and incur related expenses from these activities and such monies are handled by the Institute and accounted for as a separate fund.

NOTE 2—FINANCIAL STATEMENTS: The accompanying financial statements include, for the first time, the accounts of the IEEE Groups. In prior years, the balance of the Group's fund referred to in Note 1 was included in liabilities on the statement of financial position and the amounts which IEEE allocated to Group activities was included as an expense in IEEE's statement of income. In 1969, all income and disbursements of Groups has been reflected in the attached statement of income, and the allocation in support of the Groups is now reflected as an intrafund transfer.

As a result of this change in accounting, the operating fund balance at January 1, 1969 was increased by $569,200, the excess of total expense over income for the year 1969 has been reduced by $353,440 and the operating fund balance at December 31, 1969 was increased by $922,640.

NOTE 3—ADVERTISING: No provision for federal income taxes on advertising income earned by the Institute has been made because, in the opinion of management, the Institute had no net advertising income after allocation of direct and indirect expenses.

NOTE 4—MARKETABLE SECURITIES: Marketable securities include $109,400 deposited by certain Sections of the Institute. Such funds with pro rata share of income and unrealized gains or losses can be withdrawn by the Sections concerned at the end of any fiscal year or quarter.

NOTE 5—COMMITMENTS: In accordance with a Founder's Agreement between the Institute and the United Engineering Trustees, Inc. the Institute has agreed to maintain permanently its principal offices in the United Engineering Center, which currently involves an annual payment of approximately $190,000. The $265,000 advanced to United Engineering Trustees, Inc. is repayable only out of available reserve funds on dissolution of United Engineering Trustees, Inc. and carries interest at an annual rate of 4%.

NOTE 6—PENSION PLAN: The Institute has a voluntary noncontributory pension plan covering its employees. The pension cost for the year was $82,154 which included amortization of past service cost over 20 years. Unfunded past service cost at December 31, 1969 is approximately $174,000.