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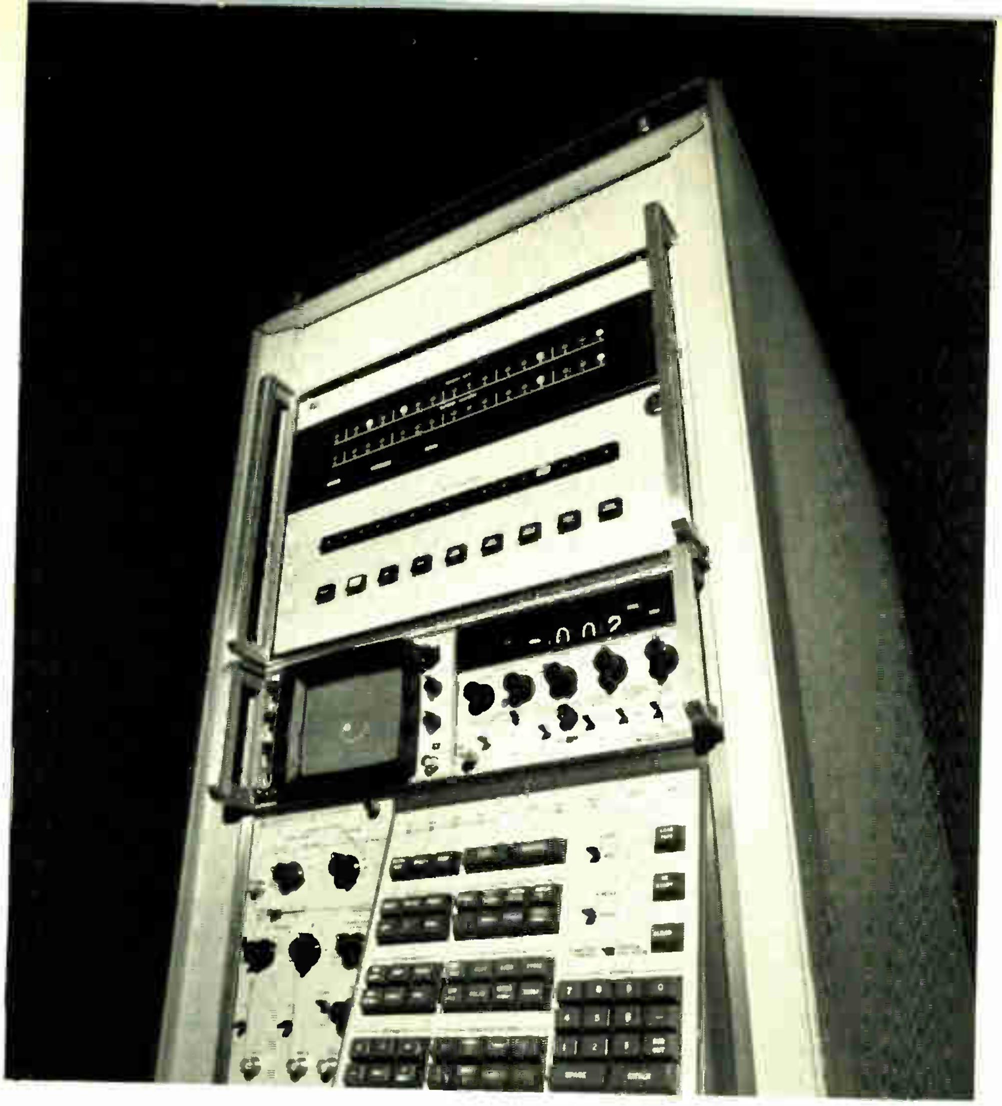

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One of the more promising industrial applications of high-power gas lasers is high-speed cutting of glass pipe, particularly in the chemical industry. The cover photo shows Avco Everett Research Laboratory experiments in high-power gas-laser cutting operations. (See article starting on page 51.)

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World Radio History

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.

Suggestions for job seekers

The article "Laid Off!" by Arthur R. Pell on page 34 of the September 1970 issue hit home—I was laid off twice in nine months from fairly responsible engineering positions.

But I think Mr. Pell's emphasis was slightly misplaced. First of all, everyone (including agencies) knows that employment agencies locate (at best) 10 percent of engineers looking for employment. Therefore, spending more than 10 percent of your effort on agencies is wasteful and accomplishes little.

Second, over 80 percent of the positions are found through personal contact. Use these contacts! An old friend (who would prefer to remain anonymous) gave me this method: Call someone—anyone—you know in your field. Don't ask him for a job! Ask him instead for a favor: the names of three people (in your field or out of it) who may need someone with your talents. This puts him at ease. He's not on the spot. He doesn't have to say "No" to you. Do the same with these three names—just ask for three names each. Keep building your pyramid. Someone, somewhere, will have a job, and since he doesn't have to say "No" he may very well say "Yes." Or at least he might say, "Come on down for an interview."

From then on, Mr. Pell's points on the all-purpose one-page résumé and the maintain-your-calm approach at an interview (easier said than done) are well taken.

And don't forget: an engineer doesn't always have to sit at a desk pushing a slide rule or punching a remote terminal. The analytical, contemplative approach engineers are supposed to have will work just as well in a hundred other fields. If one of those contacts should offer a job in marketing or advertising, well . . .

Ira M. Berman
Niskayuna, N.Y.

I would like to offer some additional commentary on the subject of conduct at an employment interview. Arthur Pell's comments in "Laid Off!" leave the job seeker with the impression that he should be satisfied with anything that he can get. What has been overlooked is that the quality of the work environment, the professional and personal expectations of immediate supervisors, and the company's ability to provide challenges are the most important ingredients of any job. The employer and employee will do far more for one another if the prospective employee evaluates the situation and his ability to contribute to it.

A good way to do this is to draw the interviewer out about his immediate problems, his plans, and his expectations. This approach also gives the job seeker an opportunity to sell himself effectively by emphasizing selected portions of his job experience, education, intelligence, and personality that will contribute to the employer's situation.

Harry A. Turner
Lex Computer Systems
Palo Alto, Calif.

The first engineering school

In his article about the role of engineers (*Spectrum*, July 1970, pp. 51–58), Dr. Maurice Ponte made an error in stating that "l'Ecole National des Ponts et Chaussées" in Paris was the first school of engineering.

In 1705 in a letter written in Czech, C. I. Willenberg, a Czech army engineer, asked the Emperor Joseph I for permission to establish a "Construction School" in Prague, the capital of the kingdom of Bohemia.

This permission was granted to him by the "Imperial Patent" in 1707. This "Patent" was also written in Czech. In 1717 Mr. Willenberg became the first professor of construction art.

It is interesting to note that in all parts of the Austrian Empire the name "engineer" was legally protected, and its use permitted only to those who had graduated from the "Polytechnic Institutes" and passed a special examination before the board appointed by the government, not by the university.

O. A. H.
Senior Member

Sources or transducers?

Mr. Walker's article on "Applications of a DC Constant-Current Source" (*Spectrum*, Sept. 1970) was comprehensive, interesting, and useful.

In fact, the devices he describes are so versatile that it seems somewhat of a misnomer to call them "*constant-current* sources." They are, in fact, voltage-to-current transducers, producing an output current in response to an input voltage, whether fixed (i.e., *constant*) or variable, internally or externally applied.

The origin of the term applied in the article relates to the constancy of output current (within design limitations) irrespective of the nature of the *load* connected, be it active or passive, simple or complex, linear or nonlinear. In this sense, it is a near-ideal Norton "constant-current generator" with extremely high internal shunt output impedance.

Pursuing the idea of the device as being a transducer rather than a source can greatly increase its applicability, because its input voltage can be the result of an analog computation (sum, product, ratio), the output of a process, the output of a D/A converter, noise generator, active filter, etc. Furthermore, operational amplifiers can be used to construct such devices as integral parts of systems, in small space and at low cost; however, the convenience of the complete instrument package cannot be denied for many of the applications described in the article.

D. H. Sheingold
Analog Devices, Inc.
Cambridge, Mass.

Laissez-faire capitalism

C. E. Hendrix (Aug. 1970 Forum, "Feedback Loops in Economics") is himself deserving of the castigation that he levels at the advocates of laissez-faire capitalism. His claim that laissez-faire is inherently unstable is merely an assertion, supported by neither reasoning nor references.

The business cycle—an oscillatory

Advance tables of contents to be reinstated

Reader reaction to the boxed notice about "Advance tables of contents," which appeared in the September issue of *Spectrum* on page 10, has been gratifying. As a result of these responses, the decision has been made to reinstate the "Advance tables of contents" starting with the January 1971 issue.

Circuits and synergy

To fill a variety of communications needs, Bell Labs and Western Electric have worked together to develop a special kind of integrated circuit. Based on two compatible and complementary technologies—silicon and tantalum—this "hybrid integrated circuit" is hundreds of times smaller and more reliable than circuits using discrete solid-state components.

The silicon portions of the circuit contain active components such as diodes and transistors; some low-precision resistors and the necessary interconnections are also formed on the tiny silicon chips. Hundreds of these chips are fabricated on one silicon slice. Tiny gold conductors—"beam leads"—are formed on each chip at the same time. Then the chips are separated and the beam leads bonded to tantalum thin-film circuits. Typically no more than one or two square inches, tantalum circuits contain precision resistors, capacitors, and interconnections etched into the metal film, previously deposited on glass or ceramic substrates.

Hybrid integrated circuits open new opportunities for circuit designers in many areas of communications systems engineering—telephone equipment, transmission, switching.

In this hybrid integration technology, design and manufacturing are intimately related. Designer and maker must work closely together. The Bell System fosters this concerted action—this synergy—with Bell Labs, for research and development, and Western Electric for manufacturing and supply. At several plants Bell Labs and Western Electric engineers work together in Process Capability Laboratories, speeding new designs into manufacture.

Here are a few examples of their teamwork.

The tantalum portion of a hybrid circuit starts as a 2000-Angstrom layer of tantalum, deposited on glass or ceramic. This process, invented at Bell Labs, was first carried out in a vacuum under bell jars. Western Electric designed and built "open ended" machines. Now, deposition takes place as the glass or ceramic chips move through the machine on a chain.

For highest precision, newly formed tantalum thin-film resistors require adjustment. This is done by removing, electrochemically, just the right amount of tantalum to raise the resistance to the required value. Bell Labs devised the process; Western Electric computerized and automated it.

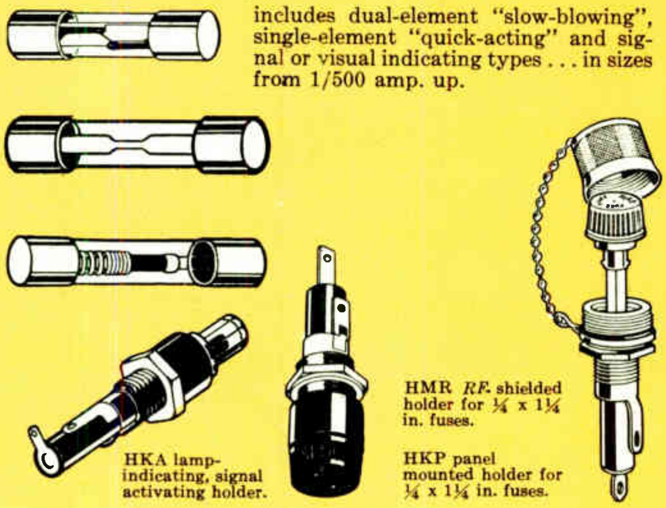
Silicon circuits are sensitive to impurities such as sodium ions in the air. So, they used to be sealed into expensive evacuated cans. But now, a gold and silicon-nitride shield gives the required protection at low cost. Originated by Bell Labs, it was put to work by Western Electric.

Making connections to integrated circuits once called for individual attachment of fine gold wires. Then Bell Labs came up with "beam leads": gold conductors plated into place on silicon circuits. In addition to being conductors, the leads also give mechanical support. Western Electric developed methods for bonding them to circuits.

Beam leads are fabricated as part of the silicon circuit but their free ends must be attached to other circuitry. Bell Labs and Western Electric have developed thermocompression bonding techniques for this job. With the proper combination of time, temperature, and pressure all leads on the silicon circuit are bonded simultaneously to a thin-film circuit.

In the future, we hope to get more circuitry into less space and to find new functions for the technology. The circuit shown here, for instance, is one of some 200 logic "building blocks" for use in private branch exchanges, data sets, and other customer telephone equipment. It could not have been built with "discrete-component" technology. And we will not stop with silicon and tantalum. For other jobs, other materials may be better. Bell Labs and Western Electric are working together to find and apply them.

Bell Labs
Western Electric



phenomenon of economic boom and bust—is an example of an important complex of feedback loops that have been rigorously analyzed by a few modern economists. Surprisingly, its causes are exogenous to laissez-faire and lie in the area of political manipulation of the money supply by means of a central banking system (see Ludwig von Mises, *Human Action;* Murray N. Rothbard, *Man, Economy, and State* and *Power and Market*).

Economics is indeed a fertile field for the application of cybernetics; however, great care must be taken to assure that the variables are defined operationally. Lack of operational definitions has led the Keynesians to write volumes of equations that have little correspondence to the real world. Politics is also an area of vital importance, which should be examined by engineers who are familiar with the tools of cybernetics. Consider the stability of politics as a system in which power, rather than profits, is the preeminent error signal.

The engineer who owns his own business can find more than mental stimulation in the systems analysis of economic and political activity—it can mean the difference between survival and bankruptcy.

D. J. Pearson
Spectrum Technology Service
Palos Verdes Estates, Calif.

I must concede that my statements concerning the probable instability of pure laissez-faire capitalism lacked supportive evidence. I was not trying, however, to assert that my ideas were incontrovertible facts, but rather was intending to point out a basic philosophical difference between right and left (economic, not political) viewpoints. This philosophical difference, I suggested, can be summarized in terms of their views about the relative stability of the system. Both extreme camps distrust and would like to replace our present system of controlled capitalism, a system that I was trying to defend.

Pearson cites authority that assigns the "cause" of the "boom and bust" cycle to political manipulation. If I read history correctly, the 19th century was characterized by economic oscillations of large amplitude, yet this was in a period during which the economy was essentially free from governmental interference. At the same time, it was a period of rapid expansion into the frontier, and it encompasses the drastic perturbation of the Civil War. Whether or not one can assign a simplistic cause to governmental control or lack of it under these conditions is, perhaps, not clear.

Implicit in my argument is the assumption that a reasonable degree of stability is a good thing, since the price for large, economic oscillations is paid for in human suffering. Although it may be, as Pearson seems to be saying, that laissez-faire economics will indeed prove to be stable, my engineering intuition tells me to be wary, and not remove the stabilizing loops that have been applied until the theory is better understood than I believe it is now. Control engineers are certainly numbered among those who are capable of understanding the theory, and one can hope that some of them will be called upon to try.

Pearson's ideas for the cybernetic analysis of political systems appear to have great merit. If political power can be made a quantifiable variable (and I can see no reason why it should not be as quantifiable as "information," for example), then he may be able to make

Why I kicked the "606" habit

I'd been buying "606" signal generators for 15 years. Sure I had worked with a couple of different models when I was just the new kid in the lab. But I learned pretty quickly that when you have to *buy* one, the easy answer is the "606." After all, that's what everybody else was buying. It seemed not only right but safe.

Funny thing is that I soon found I didn't like some of the things that the "606" offered, like its frequency range and degree of accuracy. And it wasn't even an all solid state design.

I even approached a few of the older engineers with my doubts. "Look kid," they'd say, "don't rock the lab. You just keep saying '606' and keep your diode clean."

It's not easy to think clearly when you're hooked. But one day, not so long ago, I came across an article announcing a new RF signal generator. It was everything I needed in one beautiful black box. The 920A by LogiMetrics! It offered superior stability and resolution, accuracy to 60 parts per million, phenomenal spectral purity, ease of calibration and maintenance. And, it featured direct digital display. (Oh, no more separate counters to buy!)

I went shouting through the lab, "I've found it, I've found it!" I heard whispers of, "he's always been a funny duck." But the laugh was on them. The 920A turned out to be just what we all needed for a majority of our requirements. And it saved us about $1,500 per station, too. I keep getting my back slapped!

Now, I'm somewhat of a fatalist. My guess is that 15 years from now, someone will write a story like this about the 920A habit. But for now, it really is the right one to buy.

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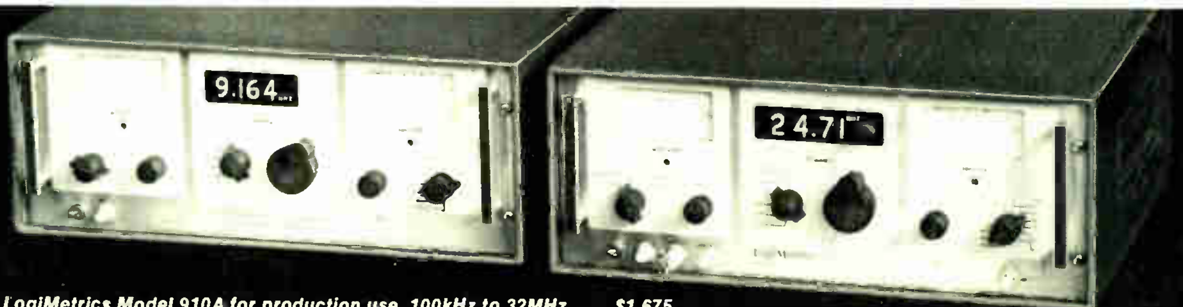

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a real contribution to the theory and practice of government.

I would suggest that systems analysis of economic and political activity can be of value to more than just those engineers who happen to own their own businesses. It may turn out to mean the difference between survival and oblivion—for all of us.

C. E. Hendrix
Pacific Palisades, Calif.

Reflection and crosstalk

In the July issue of IEEE *Spectrum* an article entitled "Reflection and Crosstalk in Logic Circuit Interconnections" appeared, which was written by John A. DeFalco.

We would like to point out that Mr. DeFalco applied Bergeron's graphical method to determine reflections and corresponding pulse shapes at both ends of the interconnecting line between two TTL digital circuits. This method was published by us about two years ago in *Electronics Letters*, volume 4, November 15, 1968, in a letter entitled "Simple Graphical Method to Determine Line Reflections Between High-Speed-Logic Integrated Circuits." This was not mentioned in Mr. DeFalco's paper.

Moreover, in the *Proceedings of the IEEE* for June 1970, our letter entitled "A New Integrated Gate Eliminating Line Reflections in High-Speed Digital Systems" appeared on page 936. In this letter, a comparison between reflection measurements and graphically deduced pulse shapes applying Bergeron's method exhibited good agreement. Also, a new integrated digital gate has been developed that eliminates these line reflections.

M. Abdel-Latif, M. J. O. Strutt
Swiss Federal Institute
of Technology
Zurich, Switzerland

M. Abdel-Latif and M. J. O. Strutt are correct; the technique used in my article is an application of Bergeron's graphical technique. I must admit that at the time I wrote my article the only reference I was familiar with was the one referenced in my article. Since this time, I have become aware of their article in *Electronics Letters*, and highly recommend it as an additional reference.

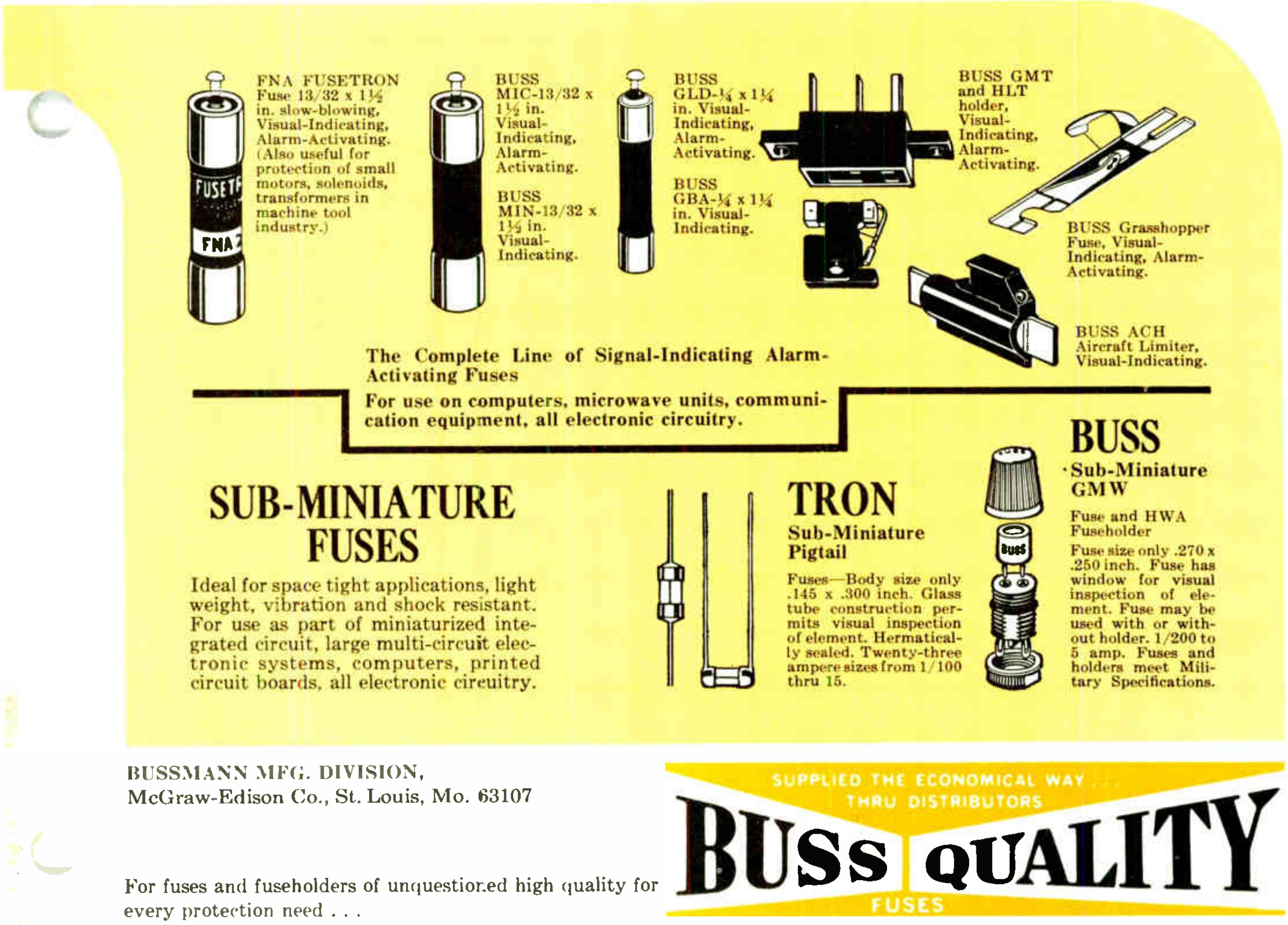
It should be noted that the "new integrated digital gate" to which they refer is in actuality an old technique with several practical limitations that prohibit its general use in eliminating line reflections.

The line terminating network has an extremely high power dissipation of between 100 and 200 milliwatts for each gate input. This severely limits the number of these networks that can be included on any integrated circuit. The high currents (20–40 mA) that give rise to this power dissipation must be sunk by the receiving gate, which calls for a special T^2L buffer circuit (SN 7440), not the SN 7400 mentioned by Abdel-Latif and Strutt.

John A. DeFalco
Honeywell Inc.
Framingham, Mass.

Correction

In John Granger's reply to T. H. McGuire's letter on page 10 of the September *Spectrum*, a mistake completely changes the meaning of Mr. Granger's thought. In the fourth line from the end of paragraph five, the correct wording should be "*that only* there are such expert judgments . . ."



VOLUME 7 □ NUMBER 11 IEEE spectrum NOVEMBER 1970

Spectral lines

What we *can* do. In "Spectral Lines" for July we considered the topic of "what we must do" with regard to the crises now besetting mankind and pleaded for engineers and scientists to turn their attention to these crises. Admittedly, even though we may want to respond to this plea, most of us in the field of electronics are puzzled about just what role we can play. Can we, with our particular specialization, contribute to reduce pollution, to control population, to eliminate war, etc.? The solutions to many of these problems require a radical change in human behavior, not just new apparatus and new systems. And, as we saw in prior discussions,[1] if our electronic talent increases information flow and improves education, then we actually do change human behavior.

However, there is a much more unusual way in which "hardware," as we often call the equipment we produce, can affect behavior; it is discussed in a fascinating article by Robert L. Schwitzgebel in the *American Psychologist*.[2] In his paper, Professor Schwitzgebel advances the interesting thesis that social behavior can be modified radically through apparatus, but not always in the direct way one might think. An example is the clock and its role in achieving acceptance of daylight saving time. If the change in behavior had been proposed by asking everyone to go to work an hour earlier, one may be sure the hue and outcry almost certainly would have led to failure. By changing the clock instead of the time, an appearance of *no change* was created, whereas in fact social behavior was markedly different. Because the changed clocks are everywhere—on our wrist, on the wall, in the timeclock—there are no undesirable perceptions, yet we retain the desirable perception of an extension of daylight in the evening.

Engineers pride themselves on their ingenuity and inventiveness. What an opportunity we have today to innovate so that desirable behavior is reinforced and encouraged by application of the right tools! Of course it would take colossal professional ego to assume that one of us could propose something to solve the major crises confronting mankind. However, the acorns from which the oaks grow may not be beyond reach. Even more attainable are those little improvements we can make in doing our own jobs better.

In this connection, the use of apparatus to increase the motivation of the working engineer comes to mind. All of us have known the time when providing an individual computer terminal, or a minicomputer, or a new test apparatus was evaluated on the basis of: (1) Is it essential to the work? (2) If not essential, would it help do the job better or faster? (3) Is it "cost effective"? But these are not the only criterions, and they may not even be important. If, as a result of providing some equipment, the engineer and his colleagues are stimulated to work harder, or they become more enthusiastic and loyal to their employer, the desirable behavior change may outweigh all rational counterarguments.

The well-known Hawthorne effect (named after the experiments in the Western Electric plant there) is a related example. In these experiments, almost every perceptible change tended to improve productive output because the very fact that *someone cares* in itself produces desirable behavior. Even if we provide some instrument or apparatus that we can't prove to have objective value, it may nevertheless be an excellent investment in its effect on people. In a reductio ad absurdum, I'm reminded of a friend who protected against burglars with a commercially printed and official-appearing sign, "This property is protected by an invisible laser beam that can cause blindness." That was clever invention since it may not even require the actual apparatus to promote the desired behavior by a would-be intruder! (In fairness, it must be pointed out that the location was one in which even burglars could be expected to have enough education to know what a laser is.)

Engineers tend to measure results in terms of objective technical and economic values rather than human values. Professor Schwitzgebel's paper suggests that there can be subjective behavior changes, good or bad, that may be more important than the intended primary effect of the technology. He opens up new uses for our apparatus and instruments, uses that can't be measured with voltmeters, oscilloscopes, and the like. Our profession in the seventies should include these social effects in our "technology assessment," and we may justify or reject new inventions and their development on these grounds alone. For those anxious to pursue the matter further, the cited article and the 44 references therein will give stimulation. In any case, adequate evaluation of the behavioral effects of our products is likely to need the cooperation of the psychologist and sociologist; IEEE can help us to work together through the Man–Machine Systems Group, and by developing relations with professional societies in the behavioral sciences.

Electronic engineers may be able, in this way, to reconcile the things they *can* do with the things that all society *must* do.

E. W. Herold, Editorial Board

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[1] Barnes, F. S., "The electrical engineer and public policy," *IEEE Spectrum* (*Spectral lines*), vol. 7, p. 21, May 1970.

[2] Schwitzgebel, R. L., "Behavior instrumentation and social technology," *Am. Psychol.*, vol. 25, pp. 491–499, June 1970.

The employment problem: Can IEEE help?

IEEE's President reviews the unfavorable economic trends currently faced by the U.S. electronics industry and their impact on employment. The question of what IEEE can and cannot do to ease the situation was faced by the Board of Directors at its last meeting, with results here reported

John V. N. Granger **President, IEEE**

The shifting patterns of the U.S. electronics industry, and the consequent rising unemployment among engineers, is a matter of great concern to the IEEE Board of Directors. It is clear that the industry of the 1970s will be different, in many respects, from that of the last decade, and that the new directions will create new challenges for IEEE members and demand new skills of them.

The U.S. electronics industry grew very rapidly from 1960 to 1969. Factory sales increased nearly 250 percent, to more than $25 billion in 1969. Though all major sectors of the industry shared in this growth, a very large proportion came in areas that "peaked out," at least for a time, in the late '60s. The NASA budget, $400 million in 1960, peaked at nearly $6 billion in 1966, fell to $4 billion in 1969, and will decline further in 1970. However, NASA's budget is likely to rise, perhaps to a level above that of the 1966 peak, in the latter years of this decade as progress on the reusable space shuttle program opens up new program options. United States shipments of commercial aircraft—a major market for electronics—peaked at $3.8 billion in 1968 after a strong growth sustained for six successive years, and declined sharply in 1969 when declining revenues forced the airlines to reschedule the huge capital outlays involved. The aviation electronics market will resume its former growth pattern, but not, in all likelihood, in the next three years.

Defense electronics, a $6 billion market for U.S. manufacturers in 1960, rose steadily until 1968, with 40 percent growth in the five years beginning in 1964, but has declined nearly 18 percent since the present Administration took office. The *total* U.S. defense budget has declined, as a percentage of Gross National Product, for five years (if expenditures for the Vietnam war are exempted) and there is every reason to expect this trend to continue through the decade. The present depressed state of defense electronics procurements is probably temporary, however, since the (as yet not contracted) electronic portions of the new weapons systems already initiated, plus the reequipment needs of the general forces, will—when and if authorized—represent a major increase in expenditure levels.

New national objectives

United States society has become deeply concerned with the deteriorating quality of the environment, the decay of the central cities, the urgently needed improvements in urban rapid transit, and the shortcomings of our health-care delivery systems, which still persist. The Congress has responded with a variety of new legislation directing intensified effort in these areas.

It should be recognized, however, that—with minor exceptions—none of these efforts represents a major current market for the electronics industry. The current emphasis is on R&D, and will remain there until appropriate new applications of technology to the solution of these problems are conceived and successfully demonstrated. Those who look to this R&D effort as a market in itself, capable of absorbing the R&D capabilities made excess by cuts in the defense and space budgets, should recognize that the *total* R&D expenditures of the Federal Government, other than on defense, space, and medicine, represent about 6 percent of the current DOD electronics budget. However aggressively the new priorities are pursued, it will be many years before the R&D manpower employed will grow sufficiently to absorb a significant portion of the IEEE membership.

Industrial electronics

Industrial electronics—computers, telecommunications, process controls, transportation electronics, etc.—outpaced all other sectors of the U.S. electronics market in its growth over the last ten years, and is currently the largest sector, with annual sales (at factory prices) in excess of $11 billion. Economists at the Stanford Research Institute forecast growth to $20 billion by 1975 and to more than $30 billion by 1980, in spite of the current "softness" of this market. Industrial electronics differs from the other major U.S. electronics markets, not only in its strong growth prospects, but also in the fact that it is rapidly developing a major *service* element. The successful application of electronics to industry requires the efforts of large numbers of engineering specialists in systems design, application engineering, installation and systems test, etc., as well as in the design and manufacture of the actual hardware. It is highly likely, therefore, that growth of the industrial electronics sector will require the services of large numbers of engineers previously employed in defense or aerospace work.

Although the summary of economic considerations presented above convinces the author that the present problems of unemployment within the U.S. electronics industry are temporary, there is no doubt of the seriousness of the current problems for many individual engineers. Neither is there any reason to believe that employment stability will be any less of a problem in the years ahead. In addition to these special problems, it is clear that the future trends of the industry will result in substantial shifts in the technical skills industry will look for in recruiting engineering specialists.

Can IEEE help?

The IEEE Board of Directors has examined each of these problem areas from the standpoint of IEEE's ability to serve its members better. It is obvious that the Institute cannot create additional engineering job opportunities at will. But IEEE does, and will continue to, serve to stimulate new contributions to engineering technology, and to present these new findings through its meetings and publications to government and industry, as well as to individual practicing engineers. This activity, which has always been the primary focus of IEEE and its predecessor societies, is indirectly a stimulus to the creation of new engineering job opportunities.

For IEEE to go further—to seek to increase Federal spending on electronics, for example—would have the immediate effect of placing the Institute's tax-exempt status in jeopardy. Even more, it would put the IEEE in the role of a "pressure group," a position that—in the opinion of the Board of Directors—would be morally repugnant to most, if not all, of our membership. Engineers, and their professional institutions, have an important role to play in informing the public, and its representatives in government, of the scientific and technical considerations that underlie the problem of choosing national goals and priorities and represent an important constraint on efforts to solve problems of public interest.

To go beyond this; to assert technical expertise or institutional solidarity as a basis for special influence in the *choice* of national goals and priorities—which is inescapably a *political* choice—would impoverish, not enhance, the professional recognition the public extends to engineers.

The problem of engineering employment instability, which has been with us since World War II, is a very real one. The IEEE cannot legally, or ethically, lobby in the Congress for legislative action in this matter. It is not at all obvious that *any* organization of engineers could obtain for its membership preferential treatment in this regard.

It is the opinion of the Board that the most constructive and effective area for increased IEEE initiatives is in the field of specialized "retraining." As described earlier, there is ample evidence that the potential employment market for certain specialized skills—the application of small-scale computers to systems simulation studies or to industrial process control, for example—is continuing to rise. In the opinion of the Board of Directors, an IEEE effort in this area is appropriate and could be uniquely effective.

Accordingly, the Board has directed the Educational Activities Board, with the close cooperation of the Executive Committee, to take immediate steps to determine which topics should be selected for the initial courses, decide which geographical areas should receive first attention, and organize and support the necessary volunteer effort and staff assistance. Further, the Board has directed the Executive Committee to review all other existing or planned programs with the objective of reducing or eliminating expenditures to a point sufficient to insure the availability of adequate financial support for the new "retraining" initiatives. This reexamination is well under way as a top-priority Executive Committee responsibility.

After careful consideration of all of the factors described above, and on the recommendation of its Long Range Planning Committee and the Executive Committee, the Board of Directors addressed itself, at its meeting on August 23, to the question of seeking a change in the tax exemption of the Institute from its present status as an "educational and scientific" organization (a category that includes all of the Founder Societies) to that of a "business league" (the category that includes the American Medical Association and the American Bar Association, as well as the National Society of Professional Engineers). The Board unanimously adopted the position that the Institute should not change its tax status from its present IRS 501c (3) to 501c (6) status.

The latter status would permit the Institute to be an active lobbyist and also represent the profession in matters of economic interest to its members. There would be considerable expense associated with this change because of the imposition of real estate taxes, sales taxes, and increased postal rates. For the Institute to be effective in these activities would also require considerable increase in the staff and facilities. No appropriate activities have yet been brought to the attention of the Board, in which the Institute could be effective, that require the change in status.

The Board will continue to direct attention to all appropriate actions that the Institute can take to assist its members during the changing conditions in which the electrical/electronics profession finds itself.

Pension plans: The state of the art

Based on a study by the Institute's General Manager, this report provides the factual background of current pension practices in the United States, particularly as they relate to the lack of vested pension rights when involuntary termination of employment occurs

Donald G. Fink **General Manager, IEEE**

The effect of termination of employment on pension benefits has become a matter of grave concern to engineers and scientists in the United States, particularly to those in the professions served by IEEE. In many cases during the postwar years, the decision to transfer from one employer to another has been a voluntary act of the professional worker and he could measure the cost of losing future pension benefits against the advantages of taking a new job. But within the last two years, a major change has occurred in the space and defense industries and their suppliers, which are so largely dependent upon government support of scientific and engineering work. In addition to discussing current pension practices in the United States, this report includes a review of activities by societies in this field, and the limitations imposed by legal and economic forces.

The public reassessment of priorities in government spending, reflected in the U.S. Congress and the Administration, has caused a massive shift of support away from work involving high technical content, in space exploration and weapons systems, for example, to programs in the fields of health, education, welfare, housing, urban development, transportation, pollution control, and the like. In these areas, for the present at least, the technical effort is not only at a substantially lower level, but is radically different in its work content. The result has been a widespread dislocation of engineers and scientists, which employees and employers alike have been unable to avoid. Termination of employment has thus largely shifted to an involuntary act, and the lack of pension benefits has little or no offsetting benefit in reemployment.

This situation has led many individual IEEE members, as well as officers and committees of the Sections and Groups, to express their concern to IEEE and to ask whether the Institute could assist its members in resolving the pension problem. Early in 1970, the IEEE Executive Committee assigned to the writer the task of investigating the trends and current status of pension plans in the United States, as pertinent background.

The present report has resulted. It is offered to the readers of IEEE SPECTRUM, not in any sense as a prescription for the ills of pension planning, but as an assessment of the practices and forces at work in this field. It is hoped that this report will be a useful source of information not only to IEEE members in the United States who may be directly affected, but also to members elsewhere who face, or will face, related issues.

The statistical background on the extent of the pension plans of the U.S. shows that their coverage is truly formidable. The total assets held in trust to guarantee pension benefits, under plans operated by nongovernment employers in the United States, have reached the monumental sum of $120 billion! Private industry retirement plans now serve more than three million retired workers with total pension payments exceeding $3 billion per year. Over 31 million employees are currently covered by pension plans of private industry.

There is abundant evidence, moreover, that pension plans in every type of employment have become more favorable to the employee in recent years. For example, eligibility requirements are being steadily relaxed; in 1960–65, 28 percent of the conventional industrial pension plans studied by the Bankers Trust Company* had no eligibility requirements; in the 1965–70 period this figure had risen to 38 percent. During the same period, the percentage of these plans requiring employee contributions dropped from 39 to 28 percent. In 1960–65, only 12 percent of the plans studied gave the employee full vested interest in his pension rights after ten years or less of service; by 1965–70, it had risen to 21 percent.

Although these trends are cause for considerable satisfaction on the part of professional workers in a time of stable employment, they are overshadowed by the fact that pension plans are not (and perhaps cannot be) devised to protect the employee in a time of unstable employment when he is forced to change jobs *before* he has achieved vested rights in his pension benefits. There is, therefore, increasing pressure to achieve such protection by reducing or eliminating altogether the service and age requirements to be met prior to vesting. How this desirable end is to be achieved, at costs that can be borne by the employer, the employee, and the government (in the form of more liberal tax treatment of pension contributions), is one of the most challenging problems facing employment managers in the U.S.

Tax deferral in pension plans

The funds from which pension benefits are paid are derived in all cases from the employer's contribution,

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* The Bankers Trust report[1] covers plans in the period 1965–70 of 201 companies with 7.8 million covered employees (about one quarter of all those covered by private industry plans).

I. Employee contributions in conventional plans[1]

Employee Contributions	1965–70 Plans	1960–65 Plans
Employee contributions on all earnings:		
Mandatory	17%	30%
Voluntary	7	3
	24%	33%
Employee contributions only on earnings over a "breaking point":		
Mandatory	11%	9%
Voluntary	9	8
	20%	17%
No employee contributions permitted or required	56%	50%
Total	100%	100%

supplemented in many instances by employees' contributions. The employer's contribution is by far the more important for several reasons. The first, and paramount, is that *amounts paid in by the employer* to pension plans qualified under the rules of the Internal Revenue Service[2] *are free of current income tax to the employee* (but are taxable when the pension benefits are received, presumably at lower tax rates). Thus the employer's contribution is a particularly important fringe benefit, and it is the lack of this benefit, and its tax shelter, that is the principal cause for concern when employment is terminated. The employee's contribution, if any, is not a factor since it is returned to the employee at termination, usually with accrued interest or other earnings. In any event, in the majority of pension plans operated by private industry, employee contributions are neither required nor permitted.*

The obverse of the tax advantage accruing to the employer's contribution is the fact that *all employee contributions* are treated as *income currently taxable to the employee*. In other words, the money contributed by the employee to his pension plan is not received in his paycheck, but it *is* added to the income reported on his W-2 Income Tax form, and he is liable for taxes on that amount. Interest earned on his contribution is not currently taxable, but this is, of course, a small amount in each tax year of the total invested by the employee, although it can assume significance over a period of years. The employee contribution is, therefore, an after-tax investment that may be compared to other investments he might make as a private individual, for example, in an annuity, mutual fund, or insurance.

Vesting of pension rights

Total lack of pension rights on termination of employment is by no means a universal experience, because in

II. Vesting provisions of conventional plans[1]

Provisions for Full Vesting	1965–70 Plans	1960–65 Plans
Vesting on completion of a period of credited service:		
10 years or less	21%	12%
15 years	11	10
20 years	8	7
25 years or more	2	1
	42%	30%
Vesting on attainment of an age:		
Age 55	3%	2%
Age 60	1	1
	4%	3%
Vesting on completion of a period of credited service ranging from five years to 25 years or more and attainment of*:		
Age 40 or less	15%	12%
Age 45	11	14
Age 50	7	13
Age 55	14	14
Age 60	3	7
	50%	60%
Vesting only on layoff	...	1%
Plans with only partial vesting	2%	3%
Plans with no vesting	2%	3%
Total	100%	100%

* Includes one plan in this study and four plans in the previous study that provide vesting only to the pension accrued after age 30.

III. Vesting provisions of pattern plans[1]

Provisions for Full Vesting	1965–70 Plans	1960–65 Plans
Vesting on completion of a period of credited service:		
10 years	34%	10%
15 years	6	1
20 years	4	...
	44%	11%
Vesting on attainment of an age:		
Age 55	1%	...
Vesting on completion of a period of credited service ranging from 10 to 25 years and attainment of:		
Age 35	3%	...
Age 40	34*	63%*
Age 45	5	6
Age 50	4	4
Age 55	3	3
Age 60	4	6
	53%	82%
Plans with only partial vesting	1%	1%
Plans with no vesting	1%	6%
Total	100%	100%

* Includes one plan in this study which provides vesting only to pension accrued after age 35 and four plans in the previous study which provide vesting only to pension accrued after age 30.

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* The Bankers Trust Company report[1] reveals that 56 percent of the "conventional" plans studied in 1965–70 neither require nor permit employee contributions (see Table I). In the 1956–59 study (seventh edition), 45 percent of the conventional plans were in the noncontributory category. In the so-called "pattern" plans all but two of the 74 studied in the 1965–70 period were noncontributory. "Conventional" plans provide benefits that vary both with years of service and with rates of compensation. The "pattern" plans studied are those that have been adopted by certain unions with individual companies and groups of companies, offering pensions based on a flat dollar rate.

the majority of pension plans, the employee may achieve, depending on his age and length of service, a vested right in his accrued benefits.* The cause of dissatisfaction here is that too large a number of employees face involuntary termination *before* they have achieved any vested interest.

The vesting provisions of pension plans involve a wide range of criterions. One basis allows full vesting after a stated period of pension-credited service with the employer. Another requires for full vesting, in addition to a stated period of credited service, that the employee shall have reached a stated age. A small number of plans (4 percent of those studied) provide only partial vesting or no vesting at all. In a very small number of cases, the degree of vesting is more liberal if the termination is involuntary, but these are so limited that their effect is not visible in the overall statistics.

It is not feasible to review here in detail the many facets of vesting, but Tables II and III, taken from the 1970 Bankers Trust Company report, summarize the major statistics in the "conventional" and "pattern" plans included in the study. These data show that full vesting is achieved in 33 percent of the conventional plans studied at the end of 15 years of credited service or less, without regard to the age of the employee, whereas in the substantial remainder of the vested plans, an age requirement is also involved, usually with credited service longer than ten years.

Vesting is required by Provincial laws in Alberta, Ontario, Saskatchewan, and Quebec, where some 75 percent of the Canadian population resides. These laws require that 100 percent of the employer's and the employee's contribution shall be vested in the employee on termination (and used to purchase an annuity payable at normal retirement), provided that he has then attained age 45 and has had ten years of continuous service with his employer. In the United States, the amount and conditions of vesting are not legal requirements (except in the Keogh Act plans described in the following). Vesting is voluntarily set up by the employer, often after negotiation with his employees, as a benefit to the employee and to the competitive position of the company.

Pension portability

Since so many employees who have faced or are facing involuntary termination have not achieved vesting of pension rights, attention has been focused on an extension of pension practice, the so-called "portable pension" with full and immediate vesting. Such plans would involve no loss whatever of any pension right earned to the date of termination, irrespective of age or length of prior service. The full accrued rights either would be available to be invested in an annuity for the benefit of the employee payable at his retirement, or would be transferred intact to his new employer, who would assign the benefits to the employee's account in the new employer's pension plan. Portability irrespective of prior service and age implies that the employee is eligible to participate in the pension plan from the starting day of his employment, and that he has an immediate vested right in all benefits that thereafter accrue to him.

IV. Pension benefits of career average plans[1]

Average Annual Compensation During Credited Service, $	Median Benefit Ranges Exclusive of Social Security, Percent
6 000	36–40
12 000	46–50
20 000	46–50
40 000	51–55

So far as the writer has been able to determine, such fully portable, completely vested pension rights are not available in any employment in the United States. A high degree of portability has been achieved in the multiemployer regional plans that have been negotiated by the labor unions, but these are restricted to a given geographical area, such as a major city and its environs. In the academic world, the Teachers Insurance and Annuity Association (TIAA) has achieved a substantial degree of portability among the pension plans of most (but not all) of the universities and independent schools in the U.S. The employing institution determines the age and/or length of service at which the employee is eligible for TIAA coverage. Once covered, the employee owns his own TIAA contract, and the employer's contributions are then fully vested.

Perhaps the most portable retirement plan is that provided by the U.S. government in the Social Security system. Benefits under Social Security do not accrue until after a period of credited service.† The employer's contribution is tax-sheltered; the employee's contribution, of equal amount, is currently taxable income. Once the eligibility requirements are satisfied, the benefits are the responsibility of the federal government, and are not affected by transfer from one employer to another (except on transfer to government employment or railroad employment, which are not covered by Social Security, but enjoy equivalent benefits, with reciprocal arrangements with the Social Security system).

Although the benefits of Social Security thus have a degree of portability not offered by other retirement plans, the extent of Social Security benefits falls short of that accruing to a professional worker under a typical industrial plan, if he spends the major part of his career with one employer. At age 65, a professional worker and his wife (assuming they no longer have children under 18) currently receive Social Security payments of about $3400 per year. In contrast, under typical private industry plans,[1] a professional worker who averaged $20 000 annual compensation during the last years of his employment prior to retirement at age 65, would enjoy at retirement a pension of from $7200 to $8000 per year, exclusive of Social Security, based on the median ranges of the plans studied. The benefit structure of such plans is illustrated in Tables IV–VI.

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*Vesting has been defined as "the right of an employee to leave the service of his employer prior to normal retirement without forfeiting his accrued pension." In the plans studied in the Bankers Trust report,[1] in 1965–70, 98 percent of the "conventional" and 99 percent of the "pattern" plans provide some form of vesting, compared with 92 and 82 percent, respectively, in 1956–59.

† "Currently insured" Social Security status is achieved after 1½ years of covered employment within the last three years prior to retirement. "Fully insured" status requires five years of covered employment for those retiring at age 65 in 1971. This will go up to ten years for those retiring at 65 in 1991 or later. The Social Security system differs from other retirement plans in that its benefits are not funded in accordance with actuarial principles, but are based on the tax concept.

V. Pension benefits of final pay plans[1]

Average Annual Compensation During Final Years of Service, $	Median Benefit Ranges Exclusive of Social Security, Percent
6 000	26–30
12 000	36–40
20 000	36–40
40 000	41–45

VI. Pension benefits of conventional plans[1]

Compensation Basis of Future Service Benefit Formula	1965–70 Plans	1960–65 Plans
All benefits based on compensation during entire period of credited service	35%	45%
All benefits based on compensation in final years of service	39	31
Only benefits based on compensation over the breaking point ranging from $3000 to $7800 based on average in final years of service. Balance of benefits based on compensation during credited service or on pattern benefits	2	3
Regular benefits based on compensation during credited service but minimum benefit based on average in final years	20	16
Other benefits based in part on compensation during credited service and in part on final years	4	5
Total	100%	100%

The essential feature of portable pension plans is that a substantial *group* of employers shall operate under the *same plan*, such that an employee leaving the employ of one member of the group can expect to find the employment he desires with another employer in the same group. Thus, when a professor who qualified for TIAA coverage leaves the employ of a university operating under a TIAA plan and joins another university operating under a similar or identical TIAA plan, he enjoys a substantial degree of portability. But if he leaves the academic world to take a job in industry, he loses much of the portability advantage. He retains his rights earned under the TIAA-plan employment, but must start fresh under the terms of the pension plan of his new industrial employer.

Pensions for the self-employed

The pension plans thus far described (other than Social Security) leave the requirements for eligibility and vesting to the employer, within guidelines established by the Internal Revenue Service, and they exclude coverage of the self-employed, i.e., sole proprietors and partners. This gap was closed in 1962 by the passage of the Keogh Act, also known as "H.R. 10."* Under this Act, as liberalized by amendment in 1966, the sole owner of an unincorporated business, or a partner owning 10 percent or more of the capital or profits interest in a partnership, may set aside each year 10 percent of his earned income or $2500, whichever is less, in trust for his retirement. The amount thus set aside is free of current income tax, the tax being deferred until he actually receives his benefits. In this manner, the self-employed can enjoy pension benefits similar in principle, if not necessarily in dollar amount, to those available to employees in industry and the academic world.

A key difference between the rules governing pensions for the employed versus the self-employed is that the Keogh Act sets eligibility and vesting requirements by law. A Keogh plan can qualify for tax deferral only if all full-time employees of the proprietorship or partnership, including the proprietor or partners, are included in the plan on and after three years' service, and only if all of the employer contributions are immediately and fully vested to the employee. Benefits may not be paid prior to age 60, and must begin no later than age 70.

Although Keogh plans are not portable (i.e., the pension rights are not transferrable from one employer to another), the provision for full and immediate vesting serves much of the same purpose. When an employee or owner–employee leaves employment covered by a Keogh plan, it is usual for his then-vested rights to be invested in an annuity payable upon retirement. If he thereupon takes employment in another firm having a Keogh plan, he loses coverage for the waiting period of up to three years, but his pension rights are fully and immediately vested under the new employer's plan. If, on the other hand, he joins a firm not covered by the Keogh Act, the eligibility and vesting provisions are determined by the plan operated by the new employer, who, in the usual case, does not offer terms as favorable as three-year eligibility plus full and immediate vesting.

Pension activities of societies

Pension benefits have been actively studied by professional societies for many years, particularly since the passage of the Keogh Act, but the degree to which such societies have been able to play an active role in the establishment of pension plans has proved to be very limited. One reason lies in the rules governing tax-deferred pension benefits cited above. To qualify for tax benefits, pension plans must be established and operated by *employers* (including self-employed employers under the Keogh Act). *Since society members are not employees of their society, no tax-benefited pension plan can be operated by a society for its members.*

This limitation rules out any additional tax-sheltered pension benefits to society members through intervention by the societies, beyond those offered presently or prospectively by the *employers* of the members. Protection of pension rights on termination is, under the present rules, reserved solely to employers, and is not subject to direct action by any other organization (including a professional or technical society) with which an employee may be associated. The opportunities open to societies are thus limited to *indirect* actions, such as (1) urging adoption of laws governing pension eligibility and vesting (an avenue open to those professional associations whose stated objectives include lobbying for legislative changes), (2) helping employers with the administrative details of tax-deferred plans, (3) devising tax-deferred plans for adoption by employers, and (4) offering non-tax-deferred investment plans.

On the legislative front, the National Society of Professional Engineers (NSPE) was active (with similar associations) in lobbying for the passage and amendment

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* The provisions of the Keogh Act are now embodied in the U.S. Internal Revenue Code, Sections 401(c, d, and e).

of the Keogh Act. The NSPE has adopted a policy statement urging employers to "improve their plans to the fullest extent possible, consistent with sound economic policies." This statement also urges that "private pension plans should vest the rights of employees at the earliest practicable time, but not more than ten years." The NSPE urged this policy in testifying before Congress with reference to proposed legislation (H.R. 1045).

Among professional societies having a majority of self-employed members (such as those serving architects, doctors, dentists, lawyers, and registered professional engineers), help has been offered to members in the establishment and administration of Keogh Act pension plans. Although the owner–employee member of such a society must set up his own plan and see that it is properly funded and administered to qualify for the tax benefits of the Keogh Act, his professional society can offer important assistance in the details. The NSPE, for example, currently offers its members the "NSPE Employers Retirement Plan (Keogh)." This society has set up a trustee (a Boston bank), which will handle the investment of the pension trust funds for this plan, split between a mutual fund and a group annuity, as determined by the employer, and will handle such details as submitting and processing the application forms to the Internal Revenue Service to qualify for tax deferral.

Non-tax-sheltered investment plans are offered by some professional societies and associations to their members as an after-tax supplement to the tax-deferred coverage they otherwise may enjoy. In some cases, such coverage forms a part of an overall pension plan offered to employers (see the following), and relates to the employee's contribution only. Individual coverage, not part of an employer's pension plan, is also available; it is, in effect, an individual investment plan (without tax benefit), for purchase of annuities or mutual fund shares, sponsored and administered by the society.

Society-sponsored pension plans for employers

A recent development is the offering by societies of pension plans having liberal provisions respecting eligibility and vesting, for adoption by those who *can* provide the all-important tax shelter, i.e., the corporate employers of society members. One such offering has recently been made ready by the NSPE, in the form of the "NSPE Employers Retirement Plan (Pension)." This is a close relative of the NSPE Keogh Plan for the self-employed, in that the society offers employers assistance in setting up the plan and arranging for its qualification by the Internal Revenue Service, and has appointed a trustee and an underwriter for annuity and mutual fund shares. It is offered to corporate employers; when qualified by the IRS, it provides the usual tax deferral of the employer's contributions to the pension trust.

To make the NSPE Employers Corporate Plan flexible enough to cover various situations among employers, it leaves open to the employer the choice of three basic criterions. First, the employer must elect the level of benefits and decide whether the compensation base shall include overtime pay, bonuses, etc. Second, he must choose whether eligibility to participate shall require no prior service, three years' continuous service, or five years of service. Finally, he must choose whether full vesting shall occur immediately, after five years, or after ten years of continuous service.

Thus, if the employer elects the most liberal of these choices in each case, his NSPE-sponsored pension plan will provide full and immediate vesting, without any service requirement, which is better than the average plan of industrial employers. But the employer may elect the least-liberal conditions, resulting in participation after five years and vesting after ten years, conditions similar to many of the major industrial plans and less favorable than some of them. Although the NSPE plan does not, therefore, put full weight behind liberal eligibility and early vesting, it does provide the basic mechanism and the administrative underpinning for a plan that can, at the employer's option, provide an excellent level of benefits.

It should be noted that the NSPE Employers Plan is not offered as a "portable plan." Even if a professional worker leaves one employer covered by the NSPE plan and joins another covered by the same basic plan, the provisions for eligibility and vesting need not be the same, and there is, in any event, no transfer of benefits or service credits.

Another society plan in prospect for employers is that recently approved in principle by the board of directors of the American Chemical Society.[3] On May 28, 1970, the ACS board gave its approval to proceed with the implementation of a pension plan, and appropriated a loan of \$105 000 for the purpose of creating an independent administrative and policy-guidance entity. The ACS-proposed profession-wide pension plan is aimed at setting up an industrial counterpart to the TIAA system. Since TIAA was founded in 1918 and now has assets of \$3.3 billion covering more than 300 000 teachers in universities and independent schools, it is recognized that fruition of the ACS efforts to the status of the TIAA system will take considerable time, possibly several decades, provided it otherwise proves viable.

The proposed ACS plan would be marketed to corporate employers, not by ACS itself, but by an entirely separate entity, such as an independent trust or corporation. The ACS estimates that a profession-wide plan for scientists and engineers would be financially viable if not less than 6000 persons were enrolled, out of the estimated 1.5 million professional people in the United States. The range of eligibility and vesting requirements is yet to be established by the trust or corporation now being formed. Figures mentioned in the current discussions are eligibility at age 25, and "early, if not immediate," vesting, with normal retirement at age 65 and actuarially reduced benefits for early retirement.

American Chemical Society spokesmen have been forthright about the prospects of attracting a sufficiently large number of employers to the plan to provide the degree of portability now offered by TIAA. In announcing the proposed plan, it was stated that the plan would initially prove attractive primarily to small employers who either have no pension plan at present, or who wish to gain a competitive edge in the hiring of professional people by offering pension rights and benefits more favorable than those of the larger corporations. As a result, the ACS stated: "Probably only 2 percent of the (ACS) members would actually be able to participate in the plan within the first three to five years."*

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* Predictably, this statement aroused correspondence from some ACS members asking, in effect: What are you doing for the other 98 percent?

It has been suggested by ACS that the plan, when instituted, could be available to employees of the larger corporations as a supplement to existing plans, whereby employees could make contributions to the ACS plan without tax benefit. Enrollment in the ACS plan by companies already having well-established plans is not expected to occur in any substantial degree unless and until noticeable competitive pressure is generated by the operation of the plan in the smaller organizations.

Despite the obstacles to be overcome, the ACS effort has been widely applauded as a step in the right direction, and its progress is being followed with great interest by other technical societies. A meeting of such societies is scheduled with ACS for this month, at which more detailed information will be given, and the possibility of participation by other societies will be explored.

Legislative activity

Pension problems have been recognized by the President and the Congress. In a message to the Congress last March, President Nixon made several specific proposals dealing with the management of pension trust funds, recommending legislation requiring that such funds be managed "exclusively in the interest of the employee beneficiaries" and mandating comprehensive reporting by all pension administrations concerning the use being made of pension funds. Nixon did not make recommendations for legislation affecting eligibility rules, early vesting, or "reinsurance" (under which the federal government would guarantee the pensions of workers of companies that had gone bankrupt).

In the Congress, two bills receiving current attention by the House Committee on Education and Labor are H.R. 1045 and H.R. 1046. H.R. 1045 contains provisions on vesting, funding standards, and benefit insurance, and H.R. 1046 deals with standards for disclosure by fiduciaries. Early passage of these measures is not anticipated by most observers of the Washingon scene, but many believe that legislation dealing with vesting, portability, and reinsurance will surely be enacted within the next decade.

Conclusion: the outlook for pension improvement

From the foregoing description of pension practice it seems reasonable to conclude that the primary problem, the lack of vesting of the employer's contribution on termination, is best attacked by liberalization of the eligibility and vesting provisions of pension plans. This is the approach taken by the Canadian laws, by the U.S. government in the passage of the Keogh Act, and by those societies who offer (or plan to offer) pension plans to employers. Such liberalization has in fact occurred as a result of the upgrading of employment benefits under the influence of competitive forces, labor negotiations, and the like. The ultimate objective is the elimination of eligibility requirements and the provision for full and immediate vesting of benefits.

The prospect of this objective being reached is determined primarily by the cost to the employer of his pension contributions, for a given level of pension benefits. Under the rules of the Internal Revenue Service, the pension funds left behind by those terminated before vesting must be returned to the pension trust for the benefit of the employees remaining in the pension plan. Such return means that the cost to the employer of maintaining the established benefit level is reduced proportionately. Conversely, liberalization of vesting requirements from, say, ten years to three, would reduce the pension fund, and the difference would have to be made up either by increases in the employer's contribution, by a reduction in benefits, or by some combination of the two.

Reduction in benefits is not considered a realistic solution to the problem as it would have to be applied to all classes of covered employees, including blue-collar workers whose ability to resist it through collective action is unquestioned. Whether increasing the cost to the employer is a feasible approach depends on *his* economic health, and this will vary from employer to employer and from industry to industry in a way that would make imposition of any universally applied liberal standards of eligibility and vesting problematical. Improvement of eligibility and vesting on a company-by-company basis is feasible, has been occurring for many years,[1] and (subject to the economic forces at work in particular industries) will no doubt continue.

Immediate eligibility plus full and immediate vesting covers most of the needs expressed by those calling for portable pensions, and such pension provisions are often confused with "portability." The additional ingredient called for in full portability is the transfer of service credits and benefits from employer to employer. As we have noted, this latter aspect of portability is realized in the Social Security system, and to some degree in the private plans of industry and the universities wherever a large number of employers are covered by the same plan. It has been argued that the TIAA plan (the principal portable plan covering professional people) initially proved feasible because university employment was distinguished by low turnover, by a comparatively low level of competitive influences, and by the fact that many university workers enjoyed "tenure" and were thus protected against involuntary termination. The conditions have changed in recent years, but a high degree of uniformity persists. By and large, uniform conditions do not exist in industrial employment, and (as we have seen in the discussion of the ACS proposals) the outlook for an industrial counterpart of the TIAA system is uncertain.

The alternative approach, to mandate a uniform set of liberal eligibility and vesting requirements on all industry by law, actually already has occurred in setting up the Social Security system. A universal level of benefits mandated by law, in effect (however it might be labeled), would constitute an extension of the Social Security system. Since the Social Security provisions are under continuous scrutiny by the Congress and the Administration, and substantial improvement of benefits has recently occurred, it may be argued that this approach is already being followed to the extent that it is acceptable to the public. All of this is not to say that further improvement of pension plan provisions is foreclosed by the political and economic forces. Improvement will come, and will probably be legally required in the next decade.

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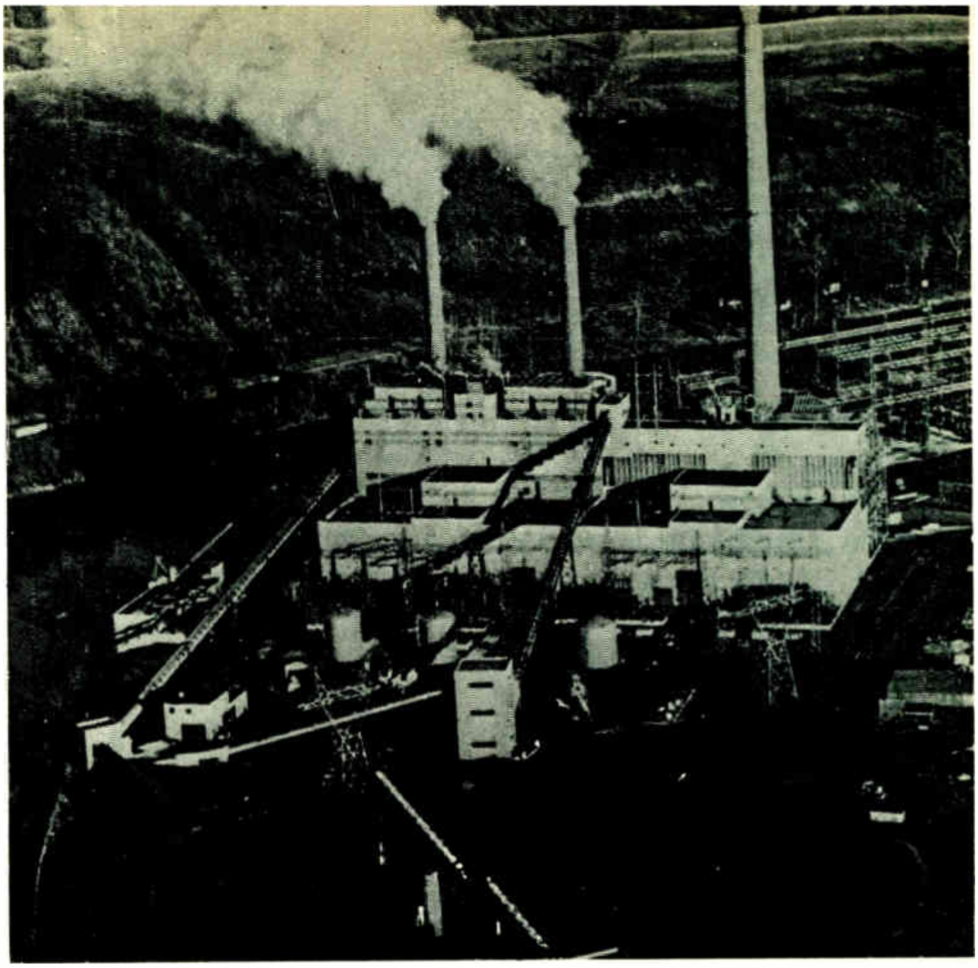


AERIAL VIEW of a coal-fired 900-MW generating station, situated adjacent to a river whose waters are used to cool the steam condensers. Both air- and thermal-pollution control measures must be applied in this plant's operation.

Power, pollution, and the imperiled environment

I. Scope of the general problem area; the planning dilemma; fossil fuel vs. nuclear; the impact of the conservationists; the coming 'saturation point' in power development; positive action programs; some control methods and devices

Saving the environment through effective pollution abatement and control is the top-priority concern for the United States—and the world. This installment explores the problems of the utilities in dealing with the present situation, and some plans for the future

Gordon D. Friedlander Senior Staff Writer

The utility companies are understandably frustrated: they are boxed into a two-way crunch of environmental conservation vs. the rising demand for electric energy. The power industry has three basic technologies to meet this demand: hydroelectric generation, steam turbogenerators, and gas turbines. But the number of natural hydro plant sites (except for pumped storage) is limited; hence little additional generation from this pollution-free source is likely. Both pumped-storage and gas-turbine plants—well suited for peaking power and emergency reserve duty—are not economical for base-load operation. Steam, the prime mover for the operation of turbogenerators, is produced either by fossil-fuel-fired boilers or by nuclear reactors. The familiar by-product of the fossil-fuel plant is air pollution through the emission of noxious gases and solid particulates into the atmosphere. The primary concern in the nuclear plant today seems to be the thermal pollution of waterways; of secondary concern is the radiation hazard. Nevertheless, the bulk of new generating capacity will be met by steam turbogenerator stations, and the projected levels of future environmental pollution will be related to this type of power generation.

To preface this series, the writer will try to avoid the extremes of public relations image building and crusading sensationalism in presenting a word picture of what the utilities are doing—or are not doing—in pollution abatement and control in the interest of protecting our common environment. To approach this objective, the writer has preferred to talk to systems engineers, staff ecologists, and environmental experts working for the power industry, and thus will rely on these interviews rather than upon the press-kit handouts or PR releases that may or may not present the pertinent facts at issue.

Review of a power ploy

"The demand for electric energy in the United States is doubling every decade." This terse and unqualified statement, repeated ad infinitum since 1966, by now has been accepted as gospel by most of us without much further thought. But now, let's think about it for a minute: this implicit formula of growth rate (see Fig. 1) is a geometric progression, to the point at which, theoretically, every available land site in the U.S. could be occupied one day by a generating station. But in practical terms, the saturation point should come—for many reasons—by the end of this century if we are to avoid approaching this absurd theoretical possibility. And unless and until revolutionary new methods of electric generation and transmission (MHD, MGD, laser transmission) are developed over the next 30 years, we can assume the continued construction of either fossil-fuel or nuclear generating plants.

One environmental expert,[1] who is the director of the environmental systems department of a major electrical supplier, believes the following environmental questions

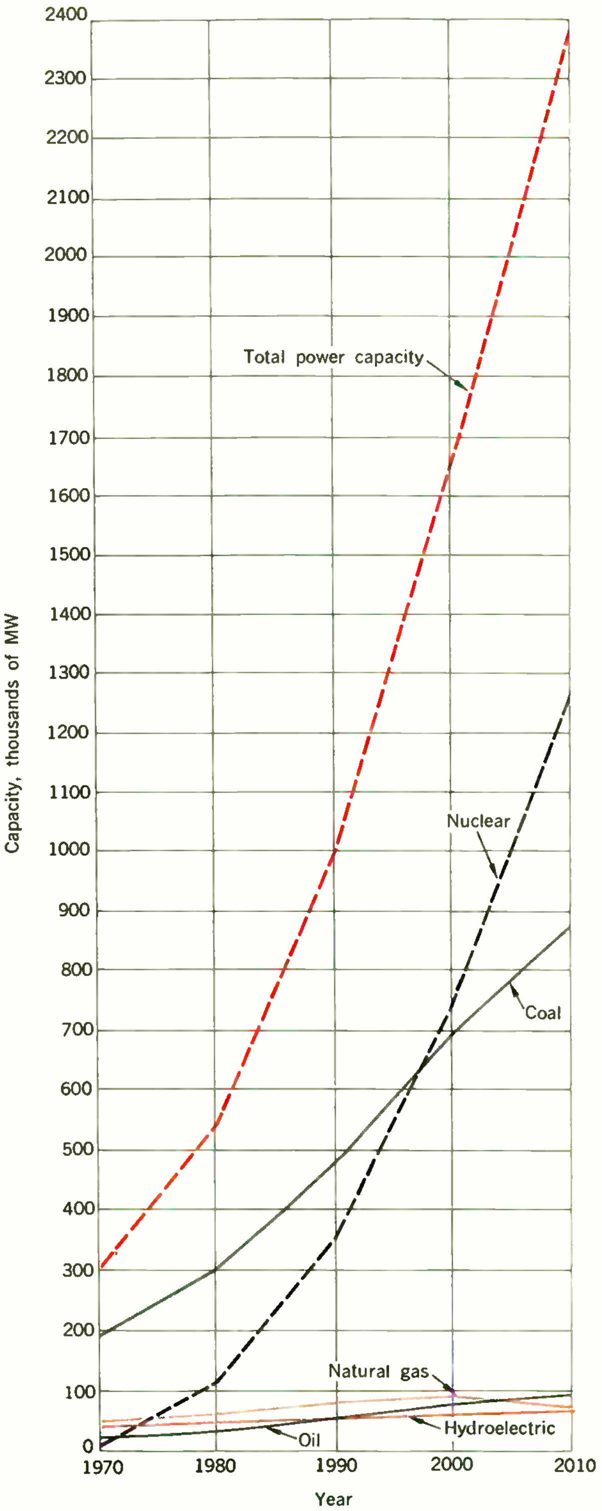


FIGURE 1. The pollution threat of the future is reflected in the exponential rise in the demand for electric power. The projected graph, prepared from government and industry data, indicates almost an eightfold increase over the next 40 years—unless the "saturation point" in the expansion of the power industry is reached before the year 2010. Note that nuclear generation will not overtake fossil fuel until about 1997.

must be answered in making an assessment of what *is* happening and what *will* happen to our environment:

- How do emissions from power plants affect the health and well-being of the general public?
- What are the standards and environmental criterions to which we can refer these emissions?
- What are the present levels of emissions from power plants and how do they relate to the total problem?
- What devices and techniques are available for improvement now and what will be needed in the future?

The 'cross forces'

Unfortunately, the general public wants to eat an ever-larger power pie—and have a clean environment, too. More and more color television sets (at average power ratings of 600 watts per picture tube) are being bought to watch soap operas, interminable sports events, quiz shows, and miscellaneous trivia during peak daytime power demand periods. And the housewife—often spurred by utility company advertising—has loaded up on a wide range of electric appliances: from air conditioners and clothes dryers to dishwashers, freezers, and toasters. Further, many new homes are completely electrified, from central heating and cooling systems to electronic ovens.

On the other hand, the conservationists, ecologists, and environmental experts are applying considerable pressure to dampen the further expansion of the power industry on the grounds that the environmental pollution produced by the belching stacks of fossil-fuel plants, and the thermal pollution of our waterways from the nuclear generating stations, are a threat to health and well-being and tend, at the least, to degrade and dehumanize our existence. The conservationists also deplore the "esthetic pollution"

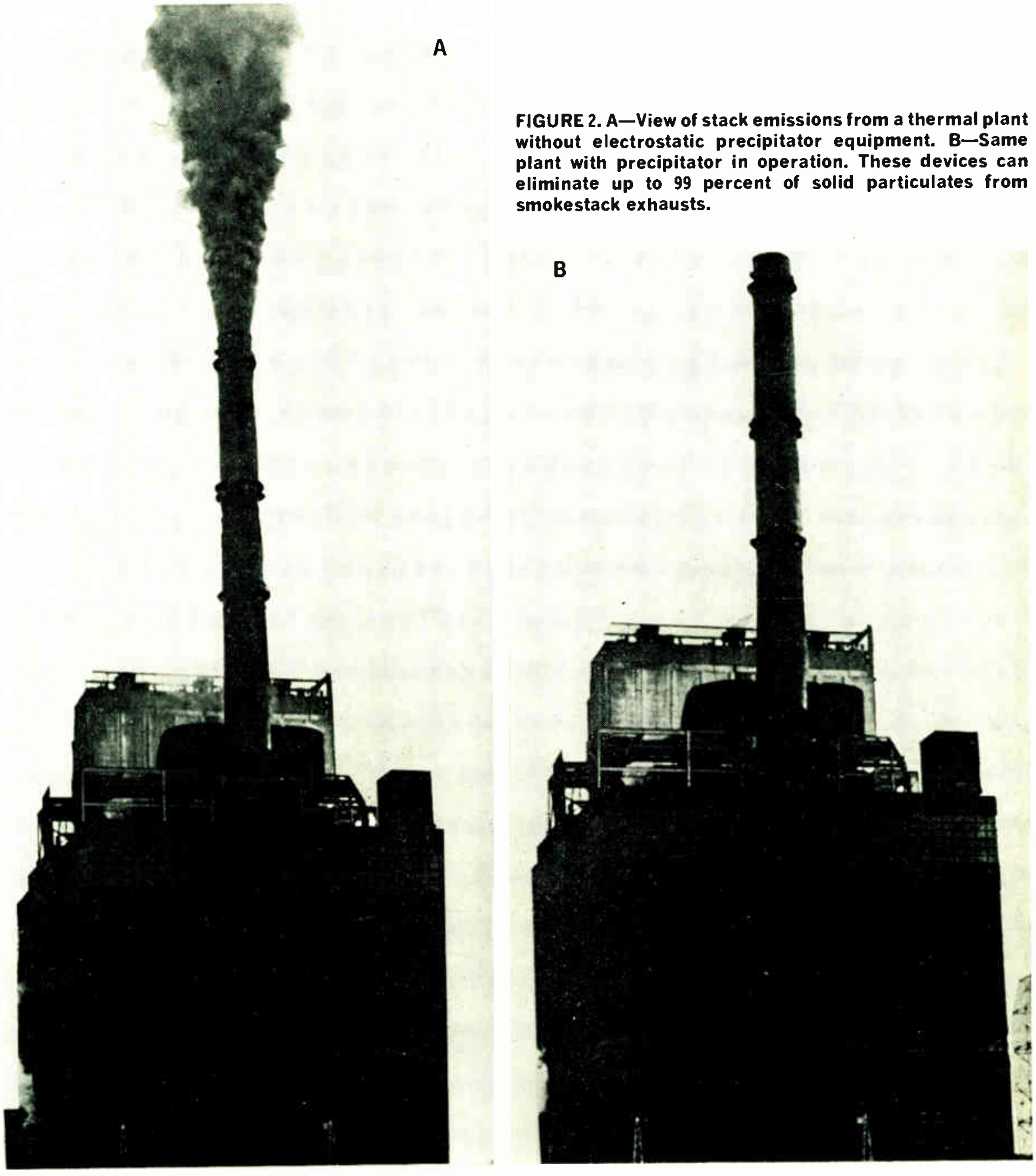


FIGURE 2. A—View of stack emissions from a thermal plant without electrostatic precipitator equipment. B—Same plant with precipitator in operation. These devices can eliminate up to 99 percent of solid particulates from smokestack exhausts.

of unsightly power plants, substations, and overhead transmission lines that slash across countless miles of our landscape.

Thus far, these groups have been successful in blocking two major utility projects on the periphery of the New York metropolitan area: Consolidated Edison's proposed pumped-storage plant at Cornwall, N.Y., and the second and third phases of Public Service's (New Jersey) Kittatinny Mountain development.

Pollution abatement and control—and diminishing returns

The utility companies feel they have been backed into something analogous to a checkmate situation: they will be damned whether they do—or don't—make a move to meet the soaring power demand. Their spokesmen cite the costly electrostatic precipitators (Fig. 2) that are installed in most thermal plants to eliminate up to 99 percent of the stack emissions of fly ash and solid particulates. But these pollution-abatement devices, in themselves, can consume more than 5 percent of a utility company's generating capacity, which quantity must then be compensated by additional generation to meet customer demand. Also, for example, the pollution-control measures taken by the steel mills in substituting electric furnaces for the open-hearth process in the manufacture of their product will require substantially more blocks of base-load generation.

Then, there is an accelerating push—in the interests of curbing air pollution from our motor-vehicle population and skyborne jet exhausts—toward the construction of high-speed all-electric mass transit systems. At first glance, such efforts have drawn praise from the public and the conservationists; but where, ask the utility people in exasperation, will this additional energy come from unless we build more and more power plants?

And so it goes in what is fast becoming a vicious circle: as industry phases out obsolescent processes and the public demands that the internal combustion engine give way to pollution-free traction and propulsive power, electric energy is most often turned toward as the primary alternative source.

Population is a factor—but so is planning

Although the population increase in the United States has been a factor in the exponential expansion of electric power demand, it should be noted that New York City's population has not grown since 1955. In spite of this, the peaking and base-load requirements have increased phenomenally—to the point where area blackouts are possible, and brownouts, or planned load shedding, are probable whenever demand exceeds generating capacity.

Con Edison's problems received considerable local, and national, attention last summer following the shutdown of its 265-MW nuclear facility at Indian Point and the forced outage of its giant 1000-MW machine at Ravenswood. Critics of the very large turbogenerators may well ask: In the interest of economy, are we putting too many "ergs" in one basket? Thirteen percent of Con Edison's generating capacity went down with "Big Allis." Nevertheless, both the utilities and the electric equipment suppliers are planning for the building and installation of single generators of up to 2000-MW nameplate capacity. Another point of valid criticism may be that some load centers are too far from points of generation, thereby necessitating the purchase and transmission of interconnected power over great distances. Such a situation played a part in triggering the Northeast area blackout of November 9–10, 1965.

The power dilemma—east and west. As early as last June, domestic users in the New York area were warned to curtail the operation of air conditioners and hot-water heaters on an "either/or" basis in the event of extended heat waves. Then, as a dramatic indication of the precarious situation in the power demand/generation ratio, the prolonged hot spell in New York City during the week of July 26 forced Con Edison to cut voltage from 3 to 5 percent in peak demand hours. (Although most electrical engineers regard a 5 percent cut as tolerable, they have reservations as to the effect of a further voltage drop—the strain on the windings of inferior-grade motors could cause many of them in domestic-appliance use to overheat and burn out.)

But New York City was not the only place where "pulling out the plug" measures had to be applied. Such action was taken regionally when the Bonneville Power Administration refused to renew contracts for firm blocks of power for the electroprocessing industries in the Pacific Northwest until scheduled new generating plants are built.

Fortunately for New York, the President came to its aid in partially alleviating the July crisis when the White House announced that the Atomic Energy Commission could provide Con Edison with "several hundred megawatts" of power. The AEC power, it was stated, could be made available by reducing operations at its uranium enrichment plants in Kentucky, Ohio, and Tennessee. Arrangements were also made with utility companies in the eastern U.S. to transmit the power, if necessary, from these AEC plant areas.

Random patterns in urban growth. Charles F. Luce, chairman of Con Edison, appeared before Senator Muskie's committee last August to give his views on the power situation in his company's service area. Mr. Luce mentioned the vast new commercial construction programs, and the large-scale housing ventures, such as the World Trade Center, Co-op City, etc., which will require about 1000 MW of base-load power in the next two or three years. These projects are built, he maintained, without prior consultation with the utility as to what potential service problems may arise; instead, the builders expect to plug in this large power demand without any difficulty. In short, they assume that a utility company is there for the express purpose of providing unlimited service for anything they choose to erect.

. . .And a reverse siting pattern in power growth. In a "letter to stockholders" contained in the Commonwealth Edison Company's 1969 *Annual Report*, J. Harris Ward, chairman of this Chicago-based investor-owned utility, makes an interesting observation: "First, large generating complexes should be located away from urban areas. These complexes can make use of several power sources. They may be fossil-fired, present-day nuclear machines, or breeder or fusion reactors. . ." And Commonwealth Edison is pursuing this policy, as we shall see in the concluding installment of this piece.

In New York City, however, there is an apparent rejection of this power-siting philosophy in Con Edison's effort to extend its existing fossil-fuel Astoria plant, which is located in a heavily populated urban area.

> "In principle, nuclear reactors are dangerous. . .In my mind, nuclear reactors do not belong on the surface of the earth. Nuclear reactors belong underground. . ."
>
> —*Dr. Edward Teller*

(It is the writer's understanding that Con Edison, in 1966, informed the city administration that it did not plan to construct any more generating stations within New York City.) Although the scheme won a narrow-margin approval from the Municipal Services Administration early in August, the decision triggered a subsequent debate within the city administration, which focused on a critical choice between the necessity of protecting the environment and the need to ensure adequate electric power. Arrayed in opposition to the approval were Environmental Protection Administrator Jerome Kretchmer and Robert N. Rickles, commissioner of New York's Department of Air Resources. Kretchmer alleged that the proposed plant extension would "emit enough pollutants to create an 'asthma alley,'" and Rickles referred to the project as "an intolerable public health problem for the city for the next 50 years."

The FPC approved the Astoria plant expansion on August 20. And Mayor Lindsay announced a compromise on August 22, when the city approved one half of the requested expansion plan: 800 MW instead of the desired 1600-MW capacity. Under the terms of the modified agreement, Con Edison will discontinue all burning of coal fuel in its plants by October 1971; will phase out its older, less-efficient generating stations; will utilize low-sulfur-content oil; and will employ natural gas fuel during air-pollution alerts in New York City. Further, the "memorandum of understanding" commits the utility to install all available air-pollution-control devices in its power plants, and to cut its stack emissions into the atmosphere to one sixth of the present discharge by 1974.

Fossil fuel, nuclear—or nothing?

A number of private utilities, temporarily thwarted in their efforts to construct additional fossil-fuel or pumped-storage facilities, next turned toward planning nuclear generating stations in which there would be virtually no conventional air pollution. But they ran into an unexpected maelstrom of opposition from the same conservationist forces. And there has also been considerable public reaction against building such plants in urban areas because of the fear of possible radiation hazards.

The matter of nuclear radiation is apparently not a black-and-white, cut-and-dried issue; rather, it is a gray area in which eminent scientists and technologists have generated a considerable degree of controversy in their disagreement.

Some pros and cons. Dr. Edward Teller—who is far from being an alarmist when it comes to the development of atomic energy—wrote in the May 1965 issue[2] of *Journal of Petroleum Technology*: "In principle, nuclear reactors are dangerous. . .The explosion of a nuclear reactor is not likely to be as violent as an explosion of a chemical plant. But a powerful nuclear reactor which has functioned for some time has radioactivity stored in it greatly in excess of that released from a powerful nuclear bomb. . .

"A gently seeping nuclear reactor can put its radioactive poison under a stable inversion layer and concentrate it onto a few hundred square miles in a truly deadly fashion . . .By being careful and also by good luck, we have so far avoided all serious nuclear accidents.

" . . .In my mind nuclear reactors do not belong on the surface of the earth. Nuclear reactors belong underground. . ."

At the annual convention of the Edison Electric Institute in 1969, Dr. Glenn T. Seaborg chairman of the AEC, stated that opponents of the nuclear reactor power generation program are guilty of "irrational thinking and activity based on misinformation and unfounded fears." And he urged the nation's utilities "to aid the AEC in its battle against opponents of nuclear power." Nevertheless, David E. Lilienthal, a former chairman of the AEC, thinks otherwise. . .

In fact, Lilienthal referred to another large question that is open to considerable debate among the experts: How do we safely dispose of the nuclear wastes from these reactors? The buildup of these wastes constitutes a growing problem. Lilienthal referred to this aspect in an article he wrote for the October 1963 issue of *McCall's*:

"These huge quantities of radioactive wastes must somehow be removed from the reactors . . . without mishap must be put into containers that will never rupture; then these vast quantities of poisonous stuff must be moved either to a burial ground or to reprocessing and concentration plants . . . with a risk of human error at every step."

And Sheldon Novick, program administrator of the Center for the Biology of Natural Systems at Washington University, St. Louis, writes in his book, *The Careless Atom*: "The wastes in these tanks pose a singularly difficult problem. The quantities of radioactivity in them are simply staggering. For instance, the maximum permissible concentration of strontium 90 in drinking water is a few billionths of a curie per gallon. Yet the wastes in storage contain an average of about 100 curies per gallon. There are now something like 65 million gallons of hot waste in storage in the AEC's 'tank farms' . . . more than enough to poison all the water on earth."

But in a recent release from Westinghouse Electric, under the heading "Westinghouse and the Environment," we find the following copy: "Some people have expressed concern that nuclear power plants will pollute the atmosphere with radioactive emissions. These fears are not based on the facts.

"Nuclear power plants in operation today discharge low-level radioactive wastes to the environment in concentrations well below levels considered safe in the recommendations . . . of commissions who have been studying and evaluating radiation effects for more than 40 years. A person living every minute at the site boundary of a Westinghouse-built nuclear power plant, drinking only the discharged water, breathing the air, and eating fish from the same water, would have to remain there constantly for more than 200 years to get the same radiation exposure effect as will result from a single chest X ray."

However, Wallace de Laguna,[3] writing in the *IEEE Transactions on Geoscience Electronics* for October 1969, has this to say in support of Lilienthal's contentions:

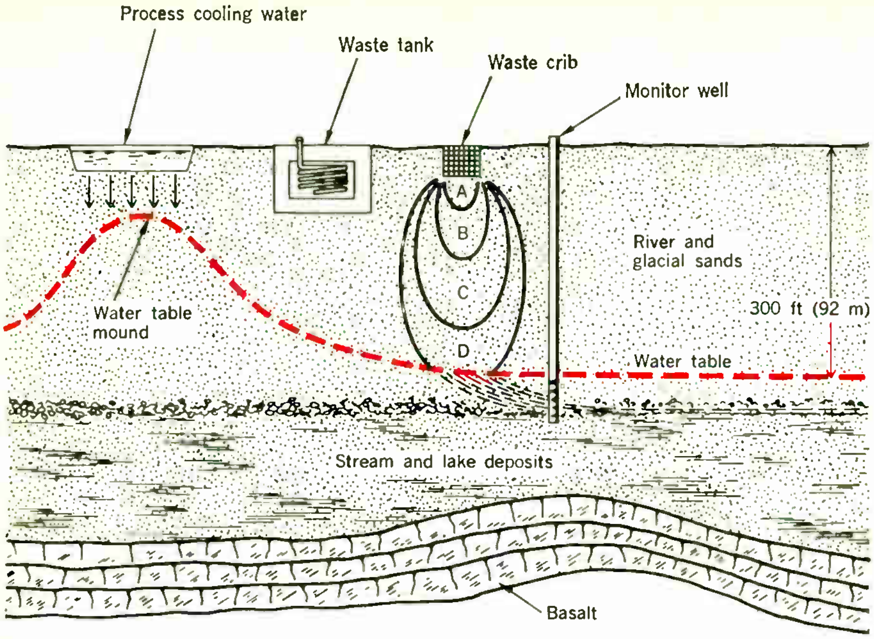


FIGURE 3. A waste-disposal crib at the Hanford (Wash.) nuclear installation. The partially decontaminated waste is run into the crib; as it seeps down, the radioactive materials are adsorbed on the soil. The materials are most easily adsorbed in zone A (near the bottom of the waste crib); the adsorption is accomplished with more difficulty in the deeper zones (B through D). Only minute quantities of the less dangerous radionuclides reach the water table, as determined by sampling in monitoring wells.

"... Until very recently, all that could be done with these nuclear wastes was to put them into large tanks ... holding in all some 80 million gallons of high-level waste which have grown up over the years at Hanford [Fig. 3], the Idaho Chemical Reprocessing Plant, and the Savannah River Plant. If the contents of even one of these tanks should reach the river which drains one of these areas, there would be a regional calamity of unprecedented magnitude... Although these tanks are constructed with great care, there have been a number of tank leaks..."

The author then says that, because of "fortuitous circumstance," almost all of the radioactive fission products in such leaks were "strongly adsorbed by soil or weathered rock, and whatever leaked out of the underground tanks was quickly adsorbed in the immediate vicinity." But de Laguna goes on to say: "An adsorptive soil forms a most valuable 'second containment,' and this environmental factor should be kept in mind in site selection... The nuclear research and fuel reprocessing center at Mol, in northern Belgium, is located over quartz sand with a remarkably low adsorptive capacity; and if any of their waste storage tanks leak, they will be forced to take heroic measures to prevent serious environmental contamination."

Two Oak Ridge nuclear scientists, Dr. K. Z. Morgan and Dr. E. G. Struxmess of the Health Physics Division at that installation, however, warned a United Nations conference on nuclear power last August that the public should be far more concerned about the amount of radiation it gets from medical treatment than that which it gets from nuclear power plants. The scientists said that nuclear power generation represents "one of the safest of all industries," and added that closer attention should be paid to the amount of radiation people get from medical treatment such as X rays.

Morgan and Struxmess were very critical of the Federal Radiation Council, which recommends standards on radiation exposure that could affect health.

For the final set of citations in this series of conflicting views, Dr. John F. Gofman and Dr. Arthur C. Tamplin of the AEC's Lawrence Radiation Laboratory stated, late last year, that current radiation health standards are too lax, and they urged the federal government to make them far more stringent. At the time, Gofman alleged that "the present standards are based on the theory that there is a threshold dose of radiation below which no harm accrues to man. However, our research shows that there is no threshold dose ... that any radiation exposure, no matter how slight, causes risks. If everyone received the Federal Radiation Council statutory allowable dose from birth, there would be a 5 percent increase in the death rate by age 30." The scientists, in testimony before Senator Muskie's (D-Maine) Subcommittee on Air and Water Pollution, alleged that "the bland reassurances of the FRC guidelines may have falsely lulled us into complacency."

Dr. Gofman admitted that, at the present time, no appreciable percentage of the U.S. population is receiving a radiation dosage near the maximum permissible (1.7 rads per year) by the FRC. But he emphasized the rapid growth of the nuclear power industry in these words: "By 1980, 20 percent of the installed power in this country will be nuclear. We have to act now before it is too late."

Essentially, then, Gofman and Tamplin asked for a reexamination of the present radiation criterions. James Graham, assistant director of the Joint Committee on Atomic Energy, conceded, in a subsequent interview, that recognized practitioners "with the scientific reputation of Gofman and Tamplin have to be considered ... when men of this caliber ask for a review, they cannot be ignored."

However, 28 eminent scientists rebutted the Gofman–Tamplin argument in a letter, dated March 30, 1970, to Congressman Chet Holifield, chairman of the Joint Committee on Atomic Energy.

Is a moratorium feasible? The Gofman–Tamplin dissent on the AEC's philosophy states, in effect, that there is no safe threshold dosage of radiation, and leukemia and cancer can be induced in humans by increases in the natural background levels. And both of these scientists allege that there is no power shortage; also, that "brownouts" are the result of artificial demand situations created by urging the public to use more and more electric appliances.

Their key recommendation, is to place a five- to ten-year moratorium on the construction of all nuclear-fission generating plants (unless built underground with all necessary operational precautions), and that fossil fuels be used until the nuclear-fusion process, presently under investigation and development, becomes practical within the next 20 years.

Human factors—and planning—in the nuclear equation

Although the direct radiation emitted in the nuclear generating process is carefully contained by shielding around the reactor, we know that small amounts of radioisotopes are released from the reactor to the environment. The construction of nuclear power plants has been proposed by industry planners in the San Francisco Bay area (which is situated in Seismic Zone 3—subject to major earthquake damage). If such a plant were physically damaged by a natural disaster—earthquake in this instance, but, say, by a tornado in a Midwest siting—would the intense heat of the fission process be sufficient to melt through the reactor and its protective casing, and permit radioactive gases to escape into populated districts?

Next question: How likely are the chances of a nuclear explosion in such a plant? Dr. Teller rates this possibility so slim as to be virtually nonexistent. But there has been at least one notable scare: the incident at the Enrico Fermi Power Plant near Detroit in October 1966. . .

Anatomy of an accident. In the Fall 1969 *Bennington Review*,[4] Dr. Irving Lyon, in his article "Nuclear Power and the Public Interest," reported that the AEC and Detroit Edison Company officials termed the Fermi plant mishap "incredible" because "a number of fail-safe devices, controlling the flow of the liquid sodium coolant in the primary circuit, failed to operate. A catastrophic accident was averted only because a worker happened to notice the erratic behavior of a dial needle and was able to shut down the plant manually."

In the fast-breeder reactor at Fermi, the liquid sodium coolant circulating through the core became temporarily blocked. Within a few seconds, the swift rise in temperature at the core twisted the tubed plutonium fuel rods out of alignment. This, in turn, further impeded the flow of the coolant. Apparently, the stoppage was caused by pieces of metal that broke loose from the bottom of the container vessel.

According to Lyon, it took more than 17 months after the incident to inspect the vessel. He writes that "the delay was inspired by fear that the meltdown might have

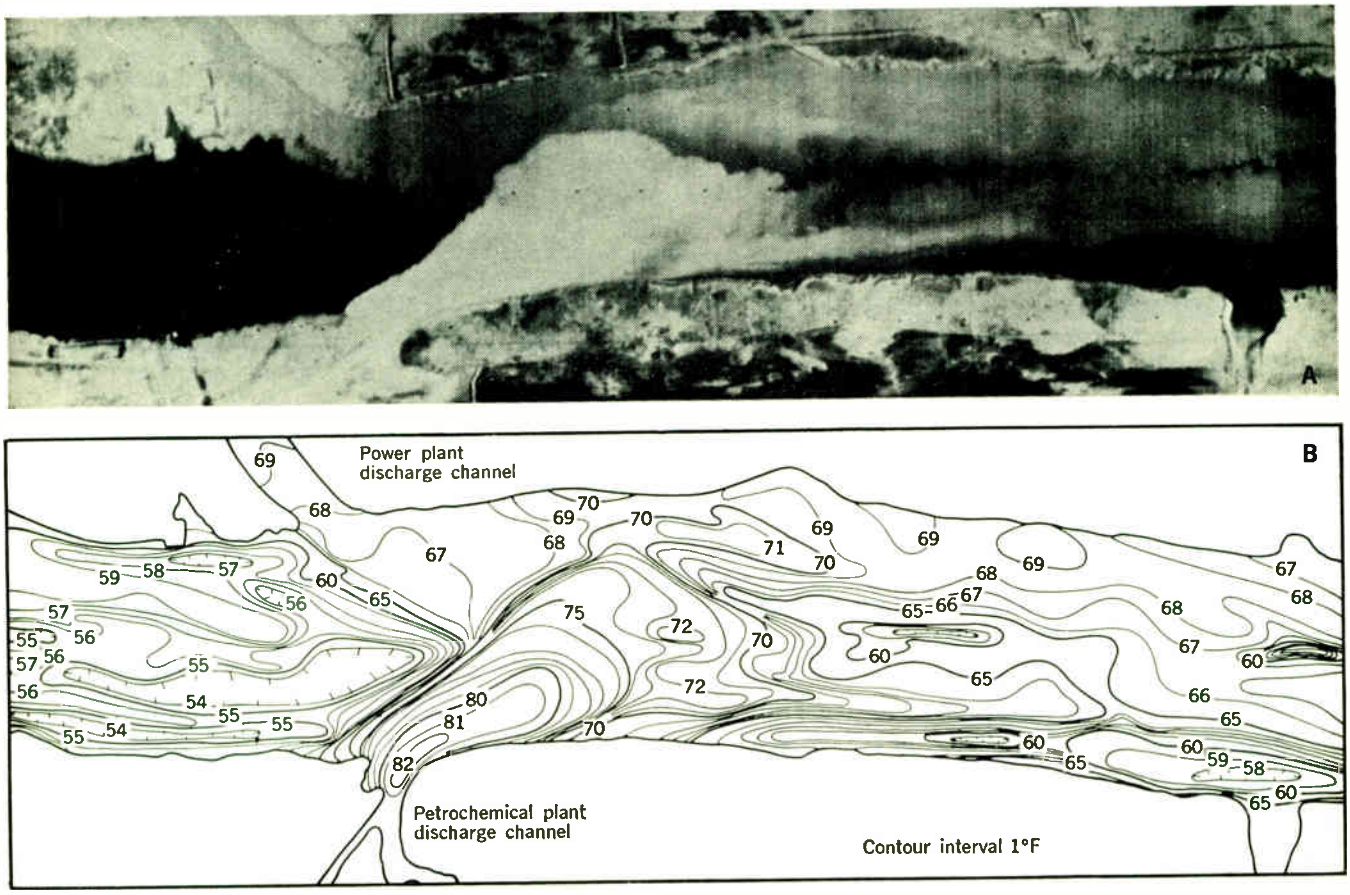


FIGURE 4. A—Infrared photo image showing the effect of two thermal effluents entering a river. B—Isothermal map compiled from the airborne scan line profiles of the photo image. (Illustrations reproduced through the courtesy of Texas Instruments Inc.)

created a critical mass of nuclear fuel. . . If it had formed, the act of probing could very well have set off an explosion with the release of unknown amounts of highly dangerous radioactivity over this heavily populated area." His final observation is that 17 months is a long time to wait for anything to become safe enough to inspect.

Is there a credibility gap? From the preceding quotations of noted scientists, science writers, and others, it is apparent that there is no consensus regarding the safety or waste-disposal problems associated with nuclear reactors. In fact, some of the expressed viewpoints are diametrically opposed. As we have noted, some experts have complete faith in the safety of present-state-of-the-art nuclear reactors, and they cite the extremely long odds against the chance of an operational accident. But Dr. David Okrent, a former chairman of the AEC's Advisory Committee on Reactor Safeguards, in Congressional testimony given in 1967, indicated "that fate is not always a respecter of enormously adverse odds." He cited an incident in power transmission, for example, in which "a mathematical impossibility had occurred; namely, one tornado took out five separate power lines to a reactor. If one calculated on the basis of probability and multiplied the probability for one line five times, you get a very small number indeed—but it happened."

And, writing in the March 1969 issue of *Natural History*,[5] Richard Curtis and Elizabeth Hogan, in their article "The Myth of the Peaceful Atom," have this to say:

"For one thing, all of us are familiar with technological disasters that have occurred against fantastically high odds: the sinking of the 'unsinkable' *Titanic*, or the November 9, 1965 'blackout' of the northeastern United States. . . The latter happening illustrates how an 'incredible' event can occur in the electric utility field, most experts agreeing that the chain of circumstances . . . was so improbable that the odds against it defy calculation."

Thermal pollution: another controversial area

Present-day nuclear reactors operate at a thermal efficiency between 20 and 34 percent; a fossil-fuel plant functions in the range of 40 to 45 percent efficiency. Thus the heat loss in a boiling water reactor (BWR) or a pressurized water reactor (PWR) can range from 80 down to 64 percent, and huge amounts of cooling water are required in these processes. For example, the temperature rise from a 500-MW nuclear plant in a river whose flow rate is 28.3 m^3/s (1000 ft^3/s) can be 8 to 10°C. According to some marine biologists and ecologists, because of the reduced oxygen content of the heated water, beneficial indigenous marine life can be killed off or driven away from a riverine habitat. And this can be the first link in a chain of ecological flora–fauna imbalance.

Conversely, in line with this reasoning, undesirable or predatory marine life, accustomed to the higher water temperature, can be attracted to the vicinity. Figure 4(A) is an infrared photo image showing two thermal effluents entering a river; Fig. 4(B) is an isothermal map compiled from the airborne scan line profiles of the photo image.

A dissenting view, and some positive programs. Some utility industry engineers and scientists, however, contend that the warmer water[6] does not have the devastating effect upon the aquatic environment that is claimed by the ecologists and environmentalists. These spokesmen maintain that the utilities contribute relatively little to the degradation of the nation's water resources; but, proportionately, they are contributing more money and know-how to water-quality improvement than any other industry.

> "I only wish it were possible to take every citizen who is seriously concerned about nuclear safety . . . and personally guide him through the planning, licensing, construction and operation of a nuclear power station. . .Then I would like to ask him to compare nuclear power with any other technology . . .and question whether any has been handled as competently, with as much integrity or with as much care and concern for the public safety and well being. . ."
>
> —*Dr. Glenn T. Seaborg*

Today, 30 states have temperature standards, and the utility companies in these states are required to design and operate their plants within the water-temperature limitations prescribed by law. Thus the companies are expending considerable sums of money in meeting these criterions by the use of dilution flow, cooling ponds, and cooling towers. In addition, almost 100 U.S. utility companies are participating in numerous hydrological environment studies that involve marine biology, thermal effects, and data on stream pollution from all sources.

Further, the utilities are engaged in exploring the beneficial uses[6] of heated discharge water for irrigation purposes and for extending the agricultural crop seasons. They believe, too, that the warmed water can be used to protect migrating water-bird flocks in artificial wintering ponds. Shrimp and lobster beds are being cultivated in such waters in Florida, and oysters are apparently being bred in a heated discharge basin on Long Island. And, in Texas, large catfish are being raised commercially by one utility in artificially warmed waters.

Role of the EEI

The Edison Electric Institute, whose membership is composed of investor-owned utility companies, is especially concerned with all of the industry's problems. Since 1962, it has sponsored research at Johns Hopkins University on the heat-exchange effects of generating plant cooling water. Last February, the EEI published "Major Electric Power Facilities and the Environment," a document prepared by its Plant Siting Task Force. The paper sets forth a series of guidelines for the siting of fossil-fuel and nuclear generating plants, hydropower facilities, and the construction of major transmission lines.

Some basic considerations in building. Under this introductory subhead, the report states in part:

"Environmental considerations are . . . significant. Major electric power facilities cannot help but have some impact on the environment. They can, however, be considerably more acceptable than many other types of industrial facilities and much can be done to reduce their impact. For example . . . thermal plants should be designed to avoid undesirable heat effects in bodies of water used for cooling. . .

"Understandably, the need of a community for reliable and economic power with which to continue to improve living conditions and the environment in which its occupants live may necessarily impinge on other environmental goals. . . Since the community where the facilities are located is most directly affected . . . the process is best accomplished by the most local forum having a responsibility for the accommodation of all such factors. . .

"Similarly, acceptance may also be sought from conservationists, sportsmen and other citizen-interest groups. Their views are also entitled to receive full consideration."

Recommendations on fossil-fuel plants. In this category, the paper urges the siting of fossil-fuel generating plants "near load centers, adjacent to adequate water and fuel supplies and with access by highway, waterway and railroad." Additional siting factors should include

1. Meteorological studies—on which the design of air-quality-control systems in the plant should be based. (These studies would comprise prevailing wind directions and velocities, ambient temperature ranges, precipitation data, and factors related to temperature inversions.)

2. Investigation of probable temperature rise in receiving bodies of water. (Significant considerations would involve the required pumping head, quantity of flow, length of intake and discharge facilities, and required circulation and variation in cooling water temperature.)

3. The air-pollution potential at a given site. (Although the utility has some degree of control over the quality of the fuel utilized, it has no control over the meteorology and topography of the area.)

4. Public acceptance. (Ample time and opportunity should be allowed for public consideration and resolution of possible conflicts concerning plant location, necessary regulatory approvals, and construction of the project.)

Nuclear generating plants. Here, the EEI report invokes the "same general criteria and considerations" applicable to a fossil-fuel plant, plus a number of "safety-related factors." It is conceded that "locating a nuclear plant is especially complicated by the fact that certain natural physical requirements must be met to provide the necessary safety margins for the protection of the health and safety of the general public."

Another paragraph recommends that the geology of an area should be examined, particularly for earthquake fault lines, after a site is found to meet population and other essential requirements. Continuing, the outline stipulates that "concern with heated water discharge is chiefly related to the possible adverse effects on aquatic life. No large nuclear plant should be sited without extensive biological studies of the waters used for condenser cooling. . ."

Another excerpt from this section of the report states that "while it would be desirable from an overall cost and reliability standpoint to locate most nuclear plants near load centers, this is not permitted by AEC criteria at this time and additional operating experience is required to change these criteria."

Two methods for removing or controlling sulfur dioxide

In the conventional fossil-fuel plant, the removal of the sulfur and nitrogen oxides from the stack gases present the biggest pollution-control headache. There are methods presently available—and they are expensive.

Cat-Ox. Monsanto Enviro-Chem Systems, for example, offers its reheat Cat-Ox system, which the manufacturer claims can convert 90 percent of the SO_2 emissions from a power plant and remove essentially all fly ash from the stack exhaust gases. Here's how it works:

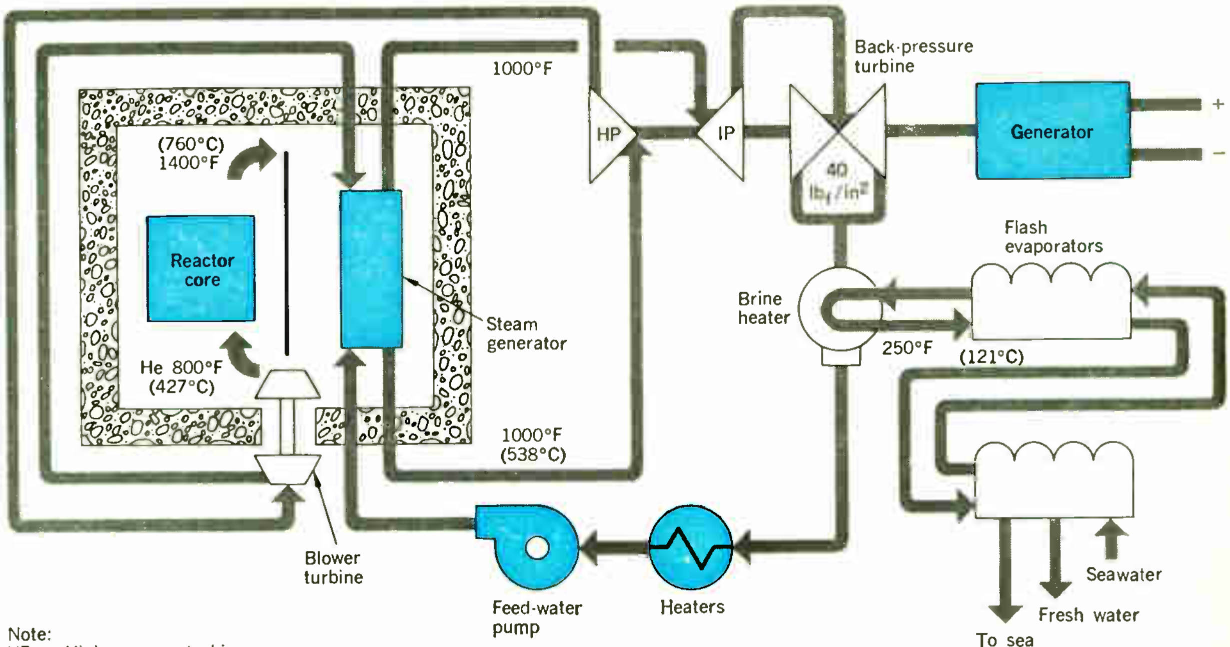


FIGURE 5. Flow diagram for a high-temperature gas-cooled reactor (HTGR) dual-purpose plant, in which seawater conversion is a by-product of power generation.

Note:
HP = High-pressure turbine
IP = Intermediate-pressure turbine

The temperature of flue gas from an existing station is usually in the range of 280° to 300°F (138°–149°C). For the conversion of SO_2 to SO_3 (sulfur trioxide), the flue gas must be cleaned and reheated to 850°F (455°C). According to Monsanto, the Cat-Ox reheat furnace is designed to maintain proper conversion temperatures regardless of boiler load. Also, the system functions independently of steam-generation equipment, and does not interfere with the power plant heat cycle. The end product is marketable sulfuric acid.

The control system can either be integrated into the construction of new power stations, or incorporated into an existing plant without limiting or interrupting present generating capacity.

Test at Boston Edison. The Boston Edison Company plans to initiate a $5 million trial project at a 150-MW thermal plant in its system for the removal of SO_2 in the exhaust stack gases. The process—jointly developed by the Chemical Construction Corporation, a subsidiary of Boise Cascade, and by the Basic Chemicals division of Basic Inc.—utilizes wet scrubbers in which particulates

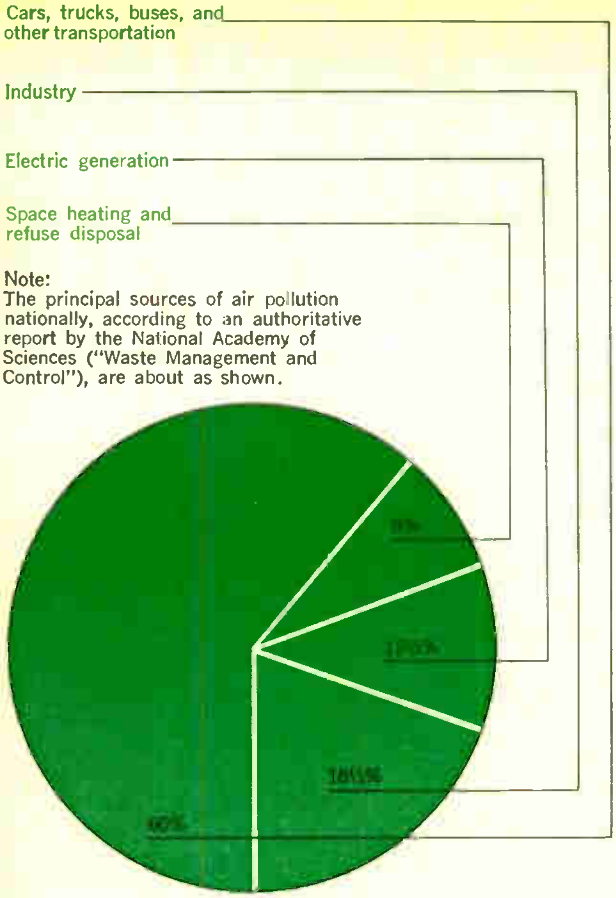
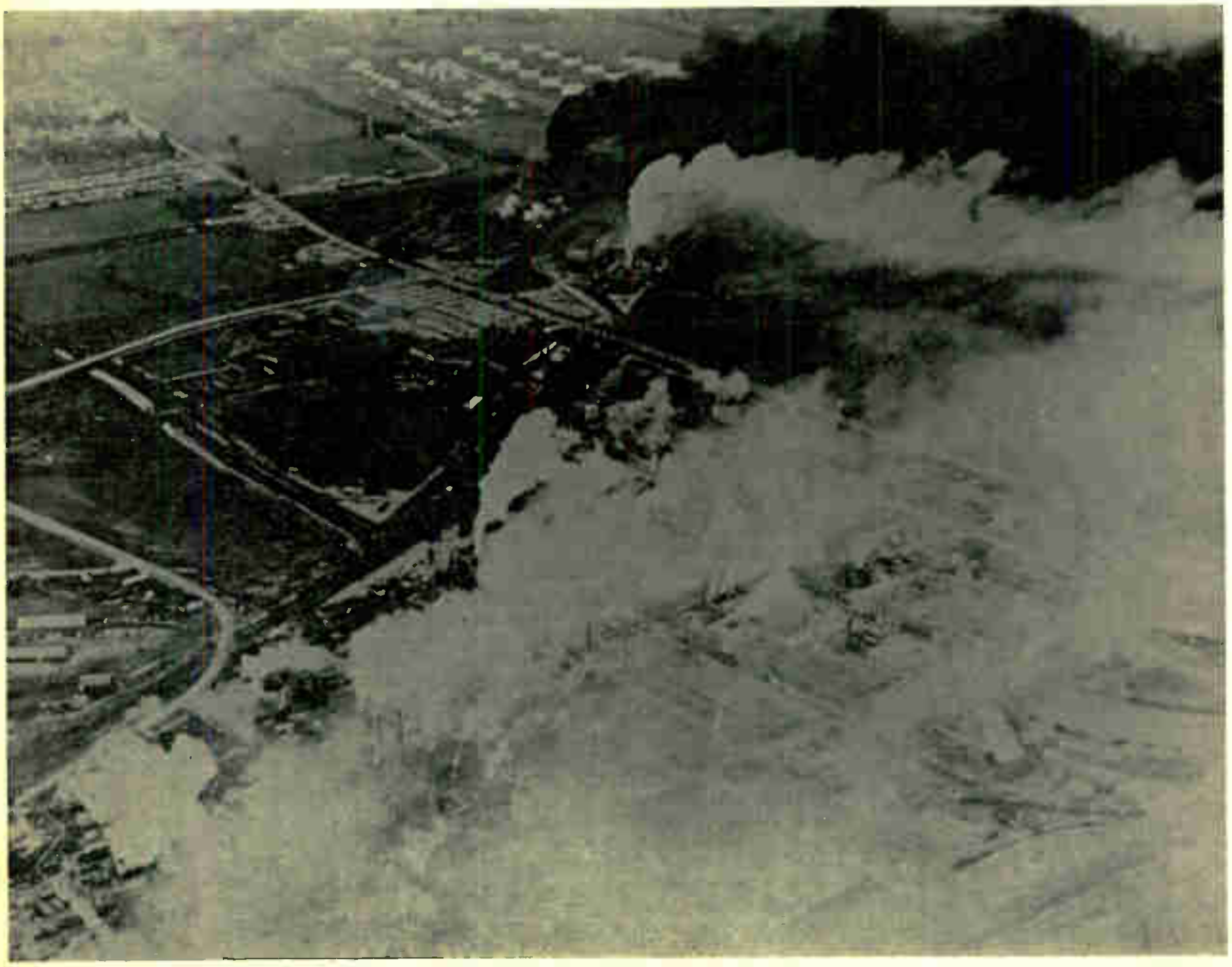


FIGURE 6. "Pie" chart, prepared by Commonwealth Edison Company, showing the distribution of pollution from all sources.

FIGURE 7. Aerial view of St. Louis, Mo., showing an area of the city under a pall of industrial air pollution.



> "First, large generating complexes should be located away from urban areas. These complexes can make use of several power sources. They may be fossil-fired, present-day nuclear machines, or breeder or fusion reactors. . ."
>
> —*J. Harris Ward*

and SO_2 gas collect on tiny droplets of water. During the scrubbing process, the SO_2 is mixed with magnesium oxide (MgO) to produce magnesium sulfite ($MgSO_3$). The $MgSO_3$ will then be shipped to the Essex Chemical Corporation's sulfuric acid plant in Clifton, N.J., where the SO_2 will be extracted for conversion either to sulfuric acid (H_2SO_4) or elemental sulfur.

The cost of the project will be borne equally by the utility and the federal government's National Air Pollution Control Administration. Some financial support may also come from the Eastern Utility Associates and the New England Gas and Electric Association.

A possible use for waste heat

The thermal-pollution problem could be diminished if practical uses could be made of the 64 to 80 percent heat losses associated with the operation of fossil-fuel and nuclear generating plants. One such solution may be found in the concept of dual-purpose plants[7] for the simultaneous production of electricity and the conversion of salt water to fresh water by either the multistage flash or other distillation methods (see Fig. 5). This would be particularly appropriate for those utilities that serve areas of existing or potential water shortage.

In a typical combination plant, steam from the turbine system is exhausted from either a back-pressure or extraction turbine to the brine heater of the distillation system, from whence the condensed steam passes to the feed-water system. This close integration of the electric generating plant and the water-conversion plant could achieve a number of thermodynamic and economic advantages.

An alternative to fossil-fuel and nuclear generation?

Recently, seven new "geothermal" steam fields were discovered in California by a University of California geophysical research team led by Robert Rex, a professor of geology. The steam fields extend from the Imperial Valley to northern Mexico. Professor Rex stated that the fields "have the potential of producing more than 20 000 MW of electric energy, and from five to seven million acre-feet of distilled water annually for the next 30 years."

The university's claim was predicated on the drilling of 100 temperature-measuring holes (sunk to depths ranging from 33 to 165 meters), tests to detect water gravity and salinity, and data from oil wells in the vicinity. (Both the Union Oil Company and the Standard Oil Company of California, however, have geothermal leases in the area, and one of the oil company spokesmen was less enthusiastic about the discovery.) Rex believes that the new power resource could revise the entire economy of the southwestern U.S. and northern Mexico through the production of pollution-free electric power.

The geothermal fields are produced when superheated rocks come in contact with cold water from underground aquifers. These steam beds are situated in widespread areas of the Imperial Valley and the Mexicali Valley of Mexico.

A Mexican geothermal power project. The Mexican government is presently building a 75-MW generating station at Cerro Prieto, which will utilize the geothermal steam to drive the turbogenerators. It is hoped that the operating experience gained in this pilot project will form the basis for tapping larger amounts of this natural thermal energy.

What to do: unplug, remain static, or expand?

The alternatives to the power dilemma are threefold: shut down a portion of the industrial and domestic load, put a lid on further industrial expansion, or meet the continuing demand for more energy and accept the environmental penalties.

The first alternative is generally unfeasible (although, as we have seen, such action had to be applied regionally in the Pacific Northwest). The second alternative is improbable for any long duration because "to remain static is to stagnate." The third course, however, is almost certain if we are to resume the upward direction of our Gross National Product.

The tradeoff between the good and bad consequences of the expansionary forces will have to be evaluated and ultimately accepted. Meanwhile, the power industry feels that much of the onus for the environmental mess is being placed unfairly at its doorstep (it claims that only 14 to 15 percent of the present pollution of the environment is from power plants). It points its own accusing finger at other industries (Figs. 6 and 7), the motor vehicle, and municipal and private incinerators as being the major contributors to the general pollution. Yet, the nagging question lurking in the background of the future continues to be: When and where will the saturation point in the generation of electric energy arrive? So far, nobody has the answer.

A look ahead: the concluding installment

In next month's issue, we shall discuss, in some detail, the plans for pollution control and system expansion of some of the major electric utilities in the East, the Midwest, and on the West Coast; touch upon the role of government—federal, state, and local—in dealing with the problems of environmental pollution; and discuss some additional proposed systems of sulfur recovery in the quest for "clean power from coal."

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Gasdynamic lasers

The population inversion necessary for lasing action in a gas can be induced by rapid expansion—without external pumping—of a hot gas mixture to supersonic speeds

Edward T. Gerry* **Avco Everett Research Laboratory**

It is not enough to depend upon diffusivity to dissipate the heat from a gas laser. Under the circumstances, average power outputs are too limited. By generating flow within the gas and deriving the benefits of forced convection, performance is improved. But if flow can be used to improve power outputs, it also can be used to advance a step further and generate the conditions that are necessary for lasing action—thereby creating a gasdynamic laser. This article covers the theory behind such a device and describes an experimental unit that has proved the merit of the concept.

The most fundamental limitation on the average power output of a laser is the waste energy resulting from inefficient operation. This waste energy may appear in the form of excited metastable states or simply as heat.

Figure 1 presents an analysis of the methods by which waste energy is removed. Most laser devices, whether solid or gas, have an active medium in the form of a long, thin cylinder. In the case of a solid, waste energy simply is conducted to the wall where it is removed by a coolant; in the case of a gas laser, energy is disposed of by diffusion of metastable states or heat to the outer walls of a cylindrical container.

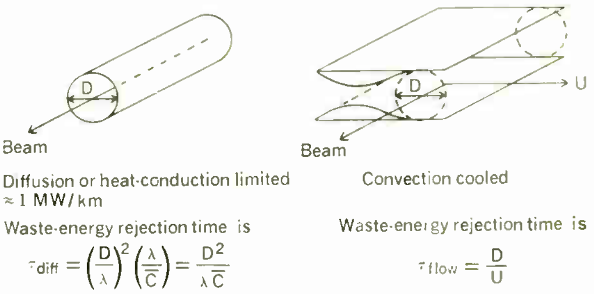

FIGURE 1. Comparison of characteristic times related to the removal of waste energy from cooled and uncooled high-average-power lasers.

With only diffusion or heat conduction to remove waste energy, a laser device, on an average-power basis, is limited to a maximum power of the order of 1 kW/m of solid-rod or gas-tube length—regardless of the diameter. However, by using high-speed flow to remove the waste energy more quickly, the average power capabilities of the device can be increased.†

For typical gas lasers, the factor by which the average power density can be increased through the use of high-speed flow[1] ranges from 10^3 to 10^5. In addition, since the flow time is independent of gas density, the density can be increased to provide still greater powers. Thus, high-speed flow can lead to larger devices that provide significantly greater average power densities than are achievable with diffusion-controlled lasers.

Table I indicates the application of flow to various classes of lasers. In electrically pumped lasers, flow can be used for removing waste energy. Excited by electron impact of, typically, "volts" energy, such electrically excited lasers as CO_2[2–7] operate at 10 μm (in the infrared); carbon monoxide[8, 9] operates around 4 μm; the copper-vapor laser[10, 11] operates in the green; and the nitrogen laser[12, 13] operates in the ultraviolet. All of these, and others, are potential candidates for the application of

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* Article adapted from a paper presented by E. T. Gerry at the American Physical Society meeting, Washington, D.C., April 1970.

† In a diffusion-controlled laser, waste energy is rejected in a characteristic time approximately that of the diffusion time T_{diff}. Because the process is random walk, T_{diff} is equal to the square of the number of mean free paths $(D/\lambda)^2$ during which the energy diffuses multiplied by the mean free time between collisions $(\lambda/\bar{C})$ and, therefore, is $D^2/\lambda\bar{C}$. Here D is the characteristic dimension of the tube, λ is the mean free path, and $\bar{C}$ is the molecular speed. But if the gas is moved at a speed U in a flowing system, waste energy is rejected in a time equal to D of the tube divided by U—i.e., D/U.

Thus, for the same active volume and gas density, the ratio of the power achievable with a stagnant and with a flowing-gas laser is simply the ratio of the characteristic times, which, as shown in Fig. 1, is equal to the characteristic dimension divided by the mean free path times the flow velocity divided by the mean molecular speed—i.e., $DU/\lambda\bar{C}$. Since the speed of sound in a gas is approximately the same as the mean molecular speed, the velocity ratio essentially is the Mach number.

I. Application of flow to various types of gasdynamic lasers

Type of Laser	Use of Gas Flow	Wavelength	Gases Used
Electrically pumped	Removal of waste energy (heat, excited states)	Widest range possible for efficient operation	CO_2, N_2, CO, Cu vapor
Chemically pumped	Removal of waste energy, temperature control, mixing, replenishing reactant	2–6 μm; longer in hybrid systems	F + HCl, F + H_2; hybrid: F + H_2 → CO_2^* (where * signifies excited molecule)
Thermally pumped	Production of gas inversion from equilibrated hot gas; removal of waste	8–14 μm for efficient operation	CO_2 at 10.6 μm

high-speed flow cooling.

In addition to electrically excited gas lasers, there are gas lasers that are either chemically or thermally pumped. But whereas the electrically pumped gas laser benefits from the application of flow only to the extent that waste energy is carried away, the chemical and thermal types depend on the flow for their lasing action.

Flow is essential to a high-power chemical laser system to replenish reactants that are consumed in the production of population inversion. (In a chemically pumped system, the active laser species is a direct product of a chemical reaction, is produced by this reaction in an excited state, and subsequently is lased.) Also in a high-speed, flowing-gas chemical laser, active variation of flow parameters may be used to achieve temperature or reaction-rate control within the laser cavity.

For efficient operation, chemical lasers typically operate in the 2- to 6-μm region of the infrared. (The chemical energy released in a reaction generally has a value corresponding to a wavelength in this range.) Operation efficiently can be extended further into the infrared in a hybrid system—wherein the energy in the excited product molecule is transferred to another molecule, which then becomes the active laser species. Examples of such chemical laser systems include those making use of the F + HCl[14,15] exchange reaction to produce excited HF, and the F + H_2 reaction,[16,17] which also produces excited HF. This excited HF energy is transferred to CO_2 and produces laser action at 10.6 μm.[18]

Gasdynamics

The final type of laser that will be described—and to which the rest of this article will be devoted—is the thermally pumped gasdynamic laser. With it, flow is used to create an inversion from what is, initially, a completely equilibrated hot gas. A thermally pumped system starts with a hot equilibrium gas mixture in which there is no population-energy inversion. The inversion is produced "gasdynamically" by rapid expansion through a supersonic nozzle.[19]

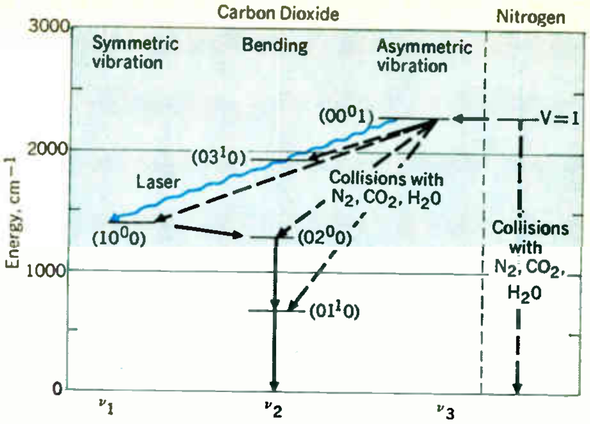


FIGURE 2. Exchanges between energy levels in a CO_2-N_2 laser. Sequential numbers relate respectively to asymmetric-stretch, bending, and symmetric-stretch mode levels. Superscript accompanying bending mode indicates the plane of vibration. V = 1 denotes first excited vibrational state.

Because a hot gas is the basic energy source, these lasers typically will operate efficiently in the 8- to 14-μm-wavelength band. The prime example of this type of laser is the nitrogen–CO_2 gasdynamic laser, operating at 10.6 μm in the standard CO_2 laser transition.

The production of vibrational nonequilibrium in CO_2 in a high-speed flow was demonstrated by Kantrowitz[20] in connection with the development of a gasdynamic method for measuring vibrational relaxation times. The inversion-production gasdynamic-method laser, in its most general form, was suggested by Basov and Oraevskii.[19] The possibility of population inversion in N_2-CO_2 mixtures by rapid expansion through a supersonic nozzle was suggested by Konyukhov and Prokhorov.[21] A similar gasdynamic approach—differential radiative relaxation in a fast expansion of an arc-heated plasma—was suggested by Hurle and Hertzberg.[22]

Figure 2 shows an energy-level diagram of the carbon dioxide and nitrogen molecules,[23] indicating the important vibrational relaxation processes that occur in such a mixture. The CO_2 gasdynamic laser typically involves a gas mixture that is mostly nitrogen, and approximately 10 percent carbon dioxide and one percent water. (Mixtures involving helium instead of water are also possible.)

Nitrogen, a simple diatomic molecule, has only one vibrational mode. Energy can be lost from this mode by collisions with nitrogen, CO_2, and water,[24] returning the excited molecule directly to the ground state. Carbon dioxide, being a linear triatomic molecule, has three basic modes of vibration: asymmetric stretch, which forms the upper laser level; symmetric stretch, which forms the lower laser level; and bending.

The energy-exchange process in the gasdynamic laser includes several transfers: (1) The very close near-resonance between nitrogen and the first asymmetric-stretch level of CO_2 causes efficient transfer of energy between these modes. Typically, the probability of this transfer at room temperature is one in every 500 collisions.[25,26] (Direct deactivation of nitrogen is relatively unimportant and energy is lost from the mixture generally through the CO_2 vibrational levels.) (2) Energy can be lost from the asymmetric-stretch mode of CO_2 by collisions with nitrogen, CO_2, and water—most probably transferring into the symmetric-stretch and bending modes of CO_2.[24,25,27-29] (However, lasing occurs only for transitions from the first asymmetric-stretch mode to the first symmetric stretch.) (3) The Fermi resonance between the bending and symmetric-stretch modes of CO_2 tightly couples these modes, Therefore, excitation energy is extracted from the lower laser level by deactivation of the bending mode—a process that can occur during collisions with all gas species, but principally water.[24]

Principle

The basic principle of the gasdynamic laser is to expand the gas rapidly through a supersonic nozzle to a high Mach number. The object is to lower the gas-mixture temperature and pressure downstream of the nozzle in a time that is short compared with the vibrational relaxation time of the upper-laser-level system (consisting of the asymmetric-stretch mode of CO_2 coupled with the nitrogen). At the same time, by addition of the catalyst (water or helium), the lower level relaxes in a time comparable to, or shorter than, the expansion time. Because of this rapid expansion, the upper-laser-level system cannot follow the rapid change in temperature and pressure and thus becomes "hung up" at a population characteristic of that in the stagnation region. Because the vibrational relaxation times associated with the upper level are long, the population will stay "hung up" for a considerable distance downstream of the nozzle. This process is known as vibrational freezing.

A basic CO_2 gasdynamic laser is presented in Fig. 3. At the top is a schematic of a supersonic nozzle. The gas flow runs from left (the stagnation region, which contains a hot, equilibrium gas mixture) to the right. A typical set of stagnation characteristics is indicated for a mixture of 7.5 percent CO_2, roughly 90 percent nitrogen, and one percent water: a temperature of 1400°K and a pressure of 17 atmospheres. (It is important to note that this is a completely equilibrated gas mixture. There is no inversion present, and since it is in an equilibrium state, this mixture can be produced in any desired way. For example, it may be produced by simply heating in a heat exchanger or nuclear reactor. Alternatively, it may be produced by combustion of a suitable fuel or by heating in a shock tube.) Typical downstream characteristics for the gasdynamic laser are an area ratio (with respect to the throat) of 14, a throat height of 0.8 mm, a Mach number of the order of 4, a pressure of about 0.1 atmosphere, and a temperature near ambient.

Figure 3(B) shows how the energy is distributed between the various degrees of freedom of the gas in a CO_2 gasdynamic laser. In the stagnation region, most of the energy is associated with the random translation and rotation of the gas molecules and 10 percent (or less) is associated with vibration. As the gas is expanded through the supersonic nozzle, the random translational and rotational energies are converted into the directed kinetic energy of flow. The vibrational energy, if it remained in equilibrium with the gas temperature, essentially would disappear downstream of the nozzle. Because of the rapid expansion, however, the vibrational energy remains "hung up" and its vibrational temperature is characteristic of that upstream of the nozzle.

Looking at this in terms of populations [Fig. 3(C)], it is apparent that the population of the lower level exceeds that of the upper level in the stagnation region, which is typical of an equilibrated gas mixture. As the gas is expanded through the nozzle, the upper-level population drops just a little bit and then remains essentially level. The lower-level population diminishes rapidly within the nozzle, continues to decrease, and virtually disappears a few centimeters downstream. Thus, downstream of the nozzle, the population of the upper level is characterized by a temperature like that of the stagnation region and the population of the lower level is characterized by a temperature like that of the downstream region. Inversion begins approximately one centimeter downstream of the nozzle throat and continues, for the gas conditions indicated in Fig. 3, for about a meter downstream of the nozzle. Because of the high gas densities involved and the high-speed flow downstream of the nozzle, an inversion capable of operation at very high powers is achieved.

General considerations

In Fig. 4, some additional considerations regarding the operation of the gasdynamic laser are presented. The flow tube has a stagnation pressure P_{stag}, stagnation tem-

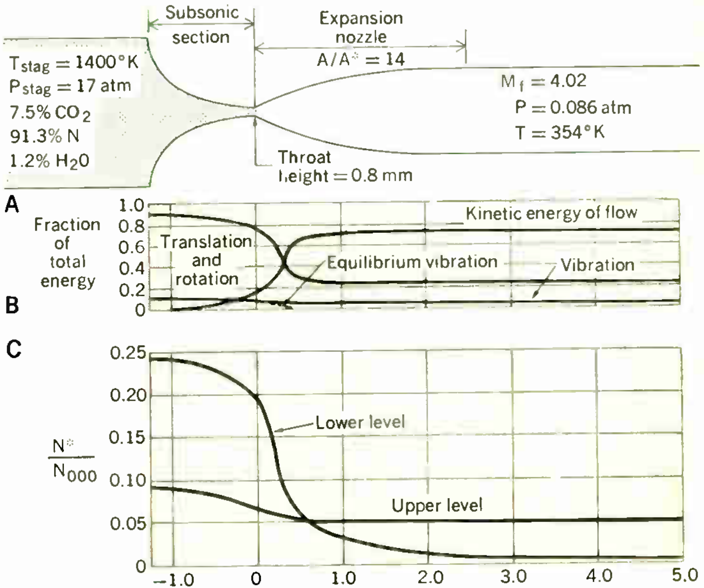
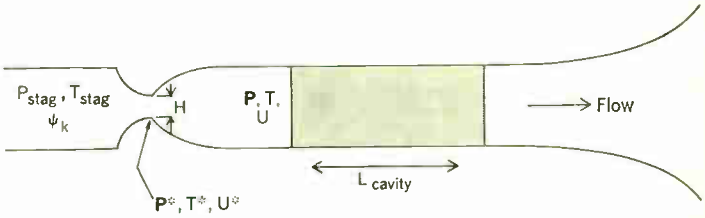


FIGURE 3. Existing conditions for a specific gas laser. N_{000} is the ground-state population. N* is an arbitrary excited state; two such states—the 100 lower and 001 upper level—are shown.

FIGURE 4. General conditions necessary for gasdynamic lasing. Diffuser (right) is only representational.



perature T_{stag}, and concentrations of species ψ_k in the stagnation region. The nozzle has a throat height H, with pressure, temperature, and velocity at the throat indicated by the starred quantities. Downstream, P, T, and U indicate pressure, temperature, and velocity in the laser cavity region—signified by the grey area—where energy is removed.

First, consider the energy that is available in the gas-dynamic laser. Per unit mass, it is essentially the vibrational energy stored in the nitrogen and CO_2 asymmetric stretch upstream of the nozzle throat. For a 10 percent CO_2, 90 percent nitrogen mixture at a stagnation temperature of 1400°K, the available laser energy (based on freezing the upper-level vibration at the stagnation temperature) is 35 J/gm of gas or 35 J/gm/s of gas flow. This maximum available energy will, of course, increase as the stagnation temperature is increased.* In any practical system, however, all of the energy available cannot be extracted because of inefficiencies and other constraints in the system. Typically only one third to one half of this available energy can be extracted from a well-designed system.

Consider what is required for efficient freezing of the upper-level vibrational energy. The maximum derivative of pressure and temperature in a supersonic flow tube occurs in the region of the throat area. Thus a typical characterizing parameter for allowable time for expansion past the throat is the ratio of the throat height to the gas velocity in the throat (which is just the speed of sound in the fluid). This flow time must be less than the effective relaxation time of the combined CO_2 and nitrogen upper laser level as it exists at the throat.† The effective relaxation time is dependent on both the temperature at the throat, and the fractional concentrations of CO_2 and water in the gas mixture; typically it is expressed in the form of a pressure–time product as it relates to gas temperature. Thus the effective time at the throat is this pressure–time product evaluated at the throat temperature divided by the static pressure (which is approximately half of the stagnation pressure) at the throat.

The effective time requirement leads to stipulations on the product of stagnation pressure and throat height in order to achieve efficient freezing of the available laser energy. For open-cycle combustion-driven systems, P_{stag} is generally fixed by conditions for diffuser-exhaust recovery to atmosphere. This relationship gives the throat

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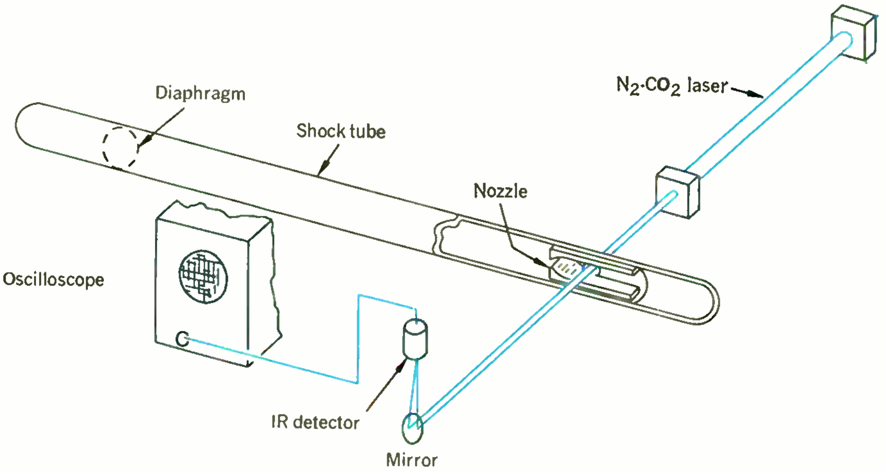
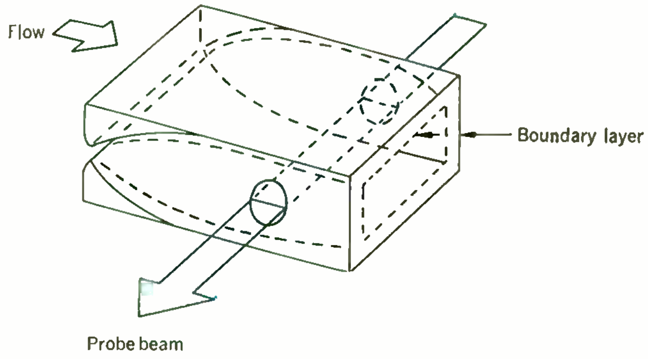
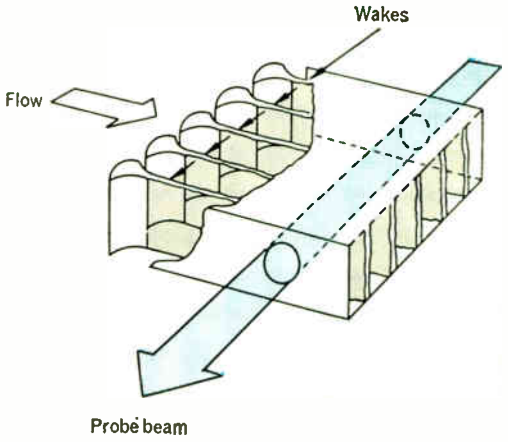
* $E_{max} = h\nu/[\exp(3380/T_{stag}) - 1]$ where h is Planck's constant, ν is the frequency, and T_{stag} is as in Fig. 4.

† That is, $H/U < (P\tau_{eff})_{T^*}/P^* \approx (P\tau_{eff})_{T^*}/0.5\ P_{stag}$ or $P_{stag}H < 2(P\tau_{eff})_{T^*}U$.

FIGURE 5. Shock-tube experiment to measure gain in an expanded N_2-CO_2 mixture. The gain-measuring apparatus outlined is said to be the most useful for ascertaining population inversion—distinction among gains of only a few percent being possible. Both single and array nozzles have been evaluated in the shock tunnel.







height as a function of CO_2 concentration and throat temperature. A downstream-to-throat-area ratio must be chosen sufficiently large that when the lower laser level has a population characteristic of the gas temperature downstream of the nozzle, its population is considerably less than the upper-level population.

In the cavity region, most of the available laser energy is stored in nitrogen. Since the energy is removed by laser action in CO_2, sufficient cavity length must be allowed for transfer of the energy stored in nitrogen vibration to CO_2. This length is simply the relaxation time for nitrogen's energy to transfer to CO_2 multiplied by the downstream flow velocity, and is inversely proportional to the concentration ψ of CO_2 in the gas mixture. Note that this is the minimum cavity length.‡ Generally the cavity must be longer, as energy removal also is limited by removal of lower-state energy by collisions with water or helium and, in most practical cases, by the allowable intracavity radiation flux.

In most gasdynamic lasers, laser-energy removal from the gas is flux-limited rather than kinetics-limited. It is important to note here that apart from vibrational deactivation, which occurs slowly downstream of the nozzle, energy not removed from the gas at a given point upstream is still available for removal downstream of that point and thus some flexibility in the design of optical cavities is possible.

Downstream, when an optical cavity is present, the rate at which quanta are generated in the cavity is equal to $G\varphi/h\nu$ quanta/cm³/s, where G is the local gain coefficient in cm^{-1}, φ is the optical flux in W/cm², and h is Planck's constant. To compute the power output of an optical cavity, φ is adjusted until the average gain of the cavity equals the total cavity loss.

Two basic versions tested

Several different gasdynamic laser devices have been operated at various facilities. These include various configurations based on shock-tube-generation and combustion-powered devices. The performance of both types of equipment are comparable—for comparable configurations—as expected. Figure 5 shows a shock-tube device together with instrumentation. Figure 6 is a schematic of a combustion-powered, 1.4-kg/s device, concerning which some details follow.

The burner is round in cross section with a 15-cm-diameter flow area and a length in the flow direction of the order of 45 cm. It joins a conical mixing chamber, also approximately 45 cm long, which expands the flow cross section to 30-cm diameter. Both cyanogen (C_2N_2) and carbon monoxide have been used as fuels in this device. The fuel is burned with air at the back plate of the burner and ignition is maintained by a methane pilot burner, which also supplies part of the water in the flow. Additional nitrogen is injected midway between the burner and the mixing chamber to provide the right gas mixture and the proper temperature.

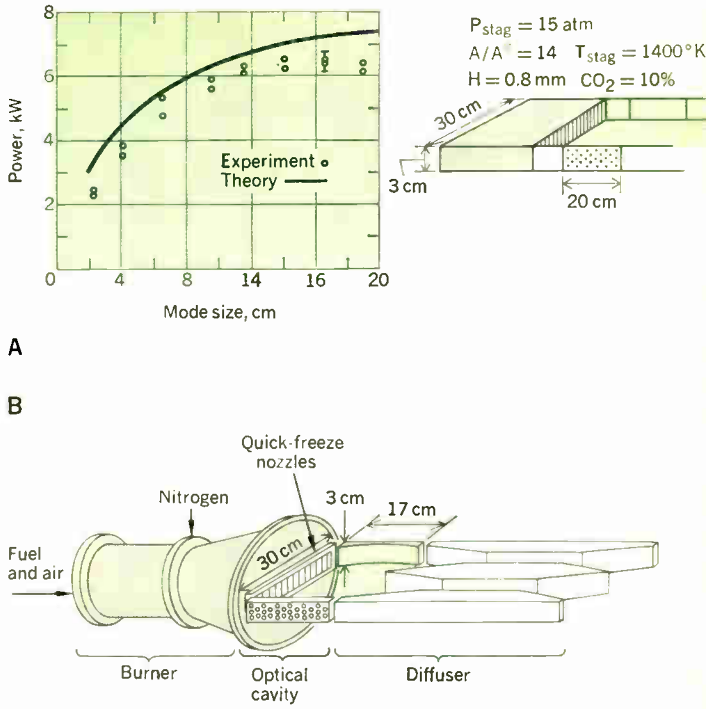
An array, 3 cm by 30 cm in cross section, consisting of nozzles containing an 0.8-mm-high throat (area ratio = 14), separates the burner from the cavity. In the cavity region, power is extracted by the use of a multihole-coupled multimode stable resonator, or by a mode-controlled unstable resonator. The former is shown in Fig. 6(A). The diffuser, which is downstream of the cavity, slows the 0.1-atmosphere Mach 4 flow to a low Mach number and raises the pressure in excess of one atmosphere so as to exhaust without pumping.

By use of the operating conditions given in Fig. 6(B), a power output of 6 kW was obtained for an operating time of 10 seconds. (The burner and nozzle row were water-cooled for steady-state operation. However, for simplicity, the cavity and diffuser, as well as the mirrors, were "heat sinked," limiting run time to the order of seconds.) Figure 7 shows the device.

Under operating conditions of the run, which produced 6 kW, the ideal laser power would have been 40 kW if complete freezing of the upper-state vibrational energy at the stagnation temperature were achieved together with 100 percent efficient energy extraction downstream. This power is a function, as discussed earlier, of the stagnation temperature and the Mach number (M). But as long as the Mach number is high enough that the lower state is well out of the way, power is relatively independent of M.

As the nozzle is not 100 percent efficient, 17.3 kW are lost to vibrational deactivation within the nozzle. This loss is a function of gas composition and the geometry of the nozzle.

FIGURE 6. A—Schematic of shock-tube-powered 1.4-kg/s gasdynamic laser and power measurements as a function of mode size. B—Exposition of combustion apparatus.



Typical Operating Conditions		Performance	
Stagnation pressure	17 atm	Power output	6 kW
Stagnation temperature	1300°K	Intracavity flux	1 kW/cm
Mach number	4.0		
Gas composition			
Carbon dioxide	8. %		
Carbon monoxide	0.2%		
Nitrogen	91. %		
Water	0.8%		
Mirror coupling	2. %		

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‡ $L_{\text{cavity min}} > (P\tau_{\text{transfer}})_T\, U/P\psi_{CO_2}$ when the flux in the cavity tends to infinity.

Boundary layers on the walls of the nozzle subtract an additional 2 kW from the available laser power. (This loss would increase whereas the incomplete freezing loss would decrease if the nozzle size were smaller.)

Because the cavity was located somewhat downstream of the nozzle exit, some collisional deactivation, accounting for a loss of 1.2 kW, occurred before the gas entered the cavity.

In addition, 2 kW were lost within the cavity.

All of these losses are controlled by gas composition, Mach number, and the location of the cavity as well as—in the case of deactivation within the cavity—by the laser flux.

Mirror losses accounted for a 10.9-kW loss, largely due to the low coupling fraction used in these experiments—2.0 percent. The copper mirrors used in the tests have a combined absorption and scattering loss on reflection of the order of 1.5 to 2 percent. Mirror loss is controlled by reflectivity, the configuration of the resonator, output coupling, and the cavity flux. The mirror in these tests had an active length in the flow direction of 20 cm. Because of incomplete extraction while passing through the cavity, there was still 1.5 kW of laser energy in the gas.

These losses total 34.9 kW, leaving a net calculated laser output power of approximately 5.1 kW, which is reasonably consistent with the measured laser power of 6 kW. The largest uncertainty is in the mirror losses.

Two points should be made with regard to laser losses: (1) The aerodynamic and kinetic processes associated with gasdynamic laser operation are now relatively well understood, and fairly accurate predictions of device performance can be made. (2) Considerable improvement in the efficiency of gasdynamic lasers can be made by improving the tradeoffs between the listed losses in order to attain a higher fraction of the ideal laser power.

Mode control in gasdynamic lasers

Since the optical cavity that exists for a gasdynamic laser is basically short and fat, geometrical angles (defined by the ratio of the cavity height to the mirror spacings) are large compared with diffraction angles (defined by the ratio of the wavelength to the cavity height). The gasdynamic laser-cavity geometry, therefore, has an intrinsically high Fresnel number. With a large combustion-powered gasdynamic laser device, the ratio of geometrical angles to diffraction angles—based on the cavity size—is of the order of a thousand; i.e., the Fresnel number is of the order of a thousand.

Figure 8 shows possible schemes for obtaining near-diffraction-limited beam outputs. The stable resonator [8(A)] is the one most commonly used in ordinary gas lasers for achieving single-mode operation. ("Stable" here refers to geometrically stable, meaning that, from geometric optical considerations, off-axis rays within certain angular limits stay in the cavity. Losses from the cavity occur only by coupling through the mirrors or by diffraction.) In order to achieve diffraction-limited

FIGURE 7. Device diagrammed in Fig. 6(B).

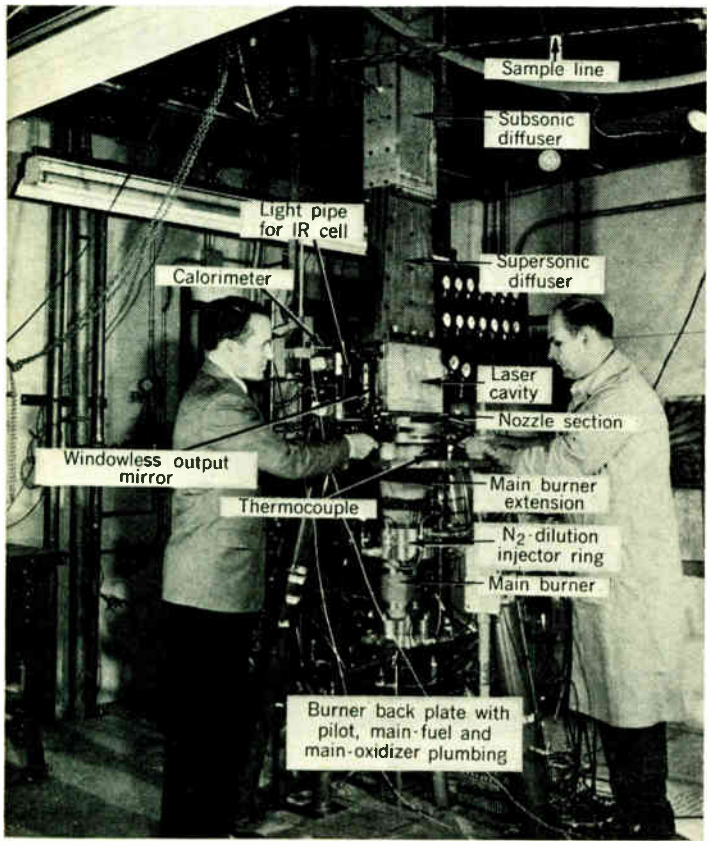
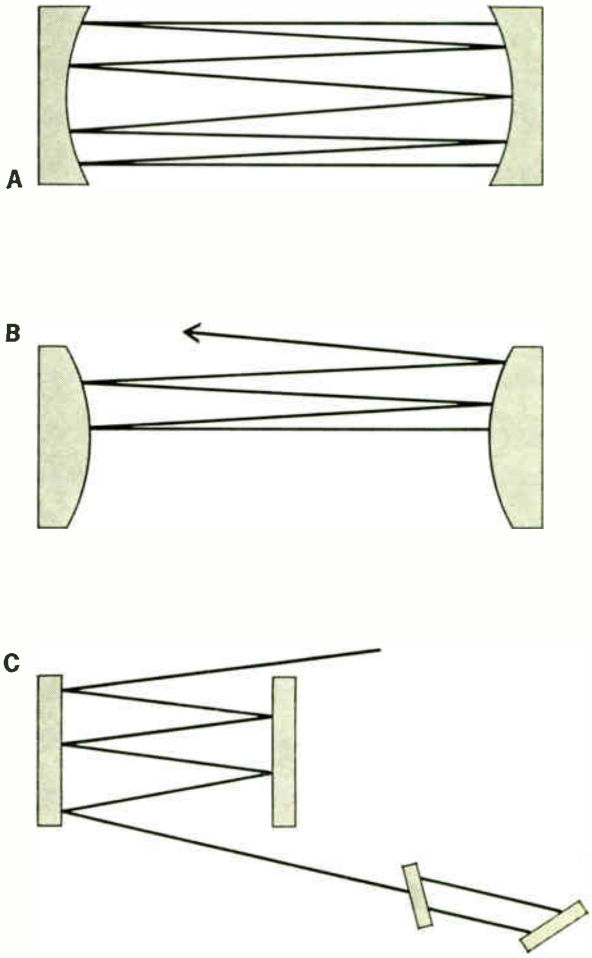


FIGURE 8. Mode-control schemes.



output (that is, minimum divergence consistent with wave optics), the stable resonator generally requires a low Fresnel number of the order of unity. Operated in this fashion, mirror-alignment requirements are less severe than for other types of resonators. In order to use this type of resonator in the high intrinsic Fresnel number medium of the gasdynamic laser, a large number of folds within the medium are required. Although this can be done, it does not appear to be the most advantageous approach to mode control in the gasdynamic laser.

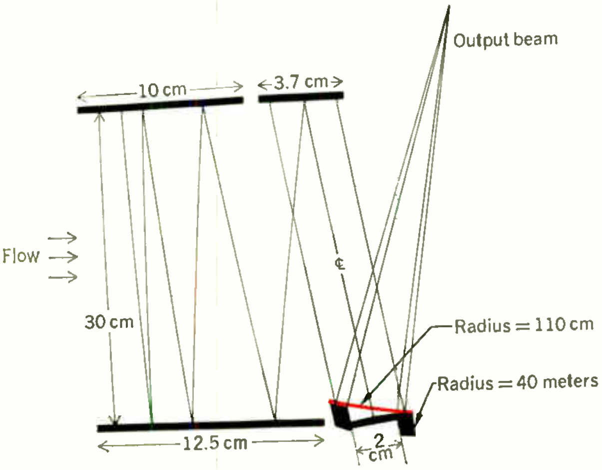
A second type of resonator is the unstable resonator,[30] in which, from geometric optical considerations, off-axis rays "walk out" of the cavity. These resonators, in principle, can operate in a lowest-order mode at any Fresnel number. They are easiest to operate when high total gain exists in the cavity so that the coupling fraction over the edge of the mirror can be large. Mirror alignment requirements are severe and are similar to those for the plane-parallel resonator. Unstable resonators appear promising for use with gasdynamic lasers, as experiments with an unstable resonator in a large combustion-driven device have shown. See Fig. 8(B).

Another approach to achieving diffraction-limited output from a gasdynamic laser is to use the master oscillator–power amplifier setup [Fig.8(C)], where the output of a low-power mode-controlled CO_2 laser is amplified by folding the beam through the gasdynamic laser using a mirror system. This system can also operate with the beam-folding geometry in the gasdynamic laser having Fresnel numbers considerably greater than unity. Alignment requirements again are severe and comparable to those for the unstable resonator. The advantage of the master oscillator–power amplifier approach is that frequency control and wavelength selection can be accomplished with the gasdynamic laser by control of these parameters in the driver oscillator.

Results were obtained with an unstable resonator (see Fig. 9) used with the combustion-driven laser. The beam path of the resonator is folded several times to increase the total gain of the system. (The plane of the folding is parallel to the flow direction.) The resonator consists of three flat mirrors and one small convex coupling mirror covering 35 percent of the area of the folded beam. The output is coupled out of the resonator over the edge of the convex coupling mirror to the outside world.

In the instance of a combustion-powered device, this output is picked up by a concentric concave mirror tilted at an angle to the system and focused out through a downstream hole so that flow disturbances introduced by entering air do not affect the optical quality of the medium. (Nor does the amount of flow exiting through the hole disturb the operation of the diffuser.) This hole location is a convenient way of circumventing the problem of suitably placing a window to handle the output

FIGURE 9. An unstable resonator. The output is coupled over the edge of the convex (40-meter-radius) mirror.



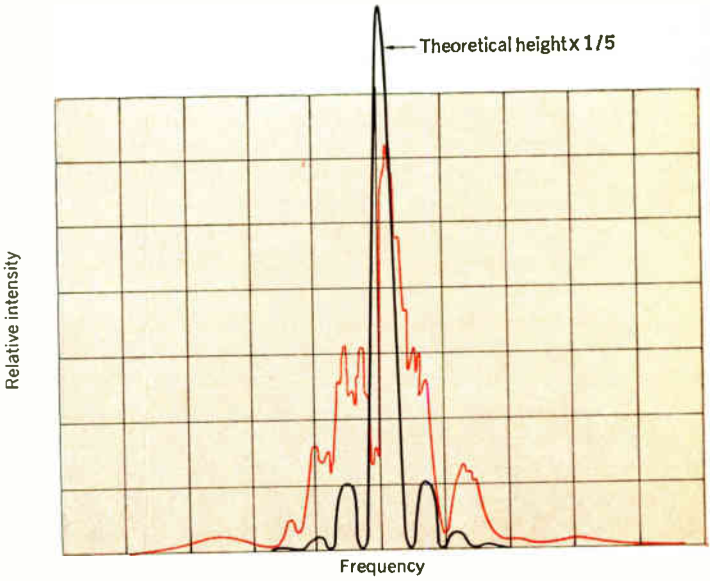
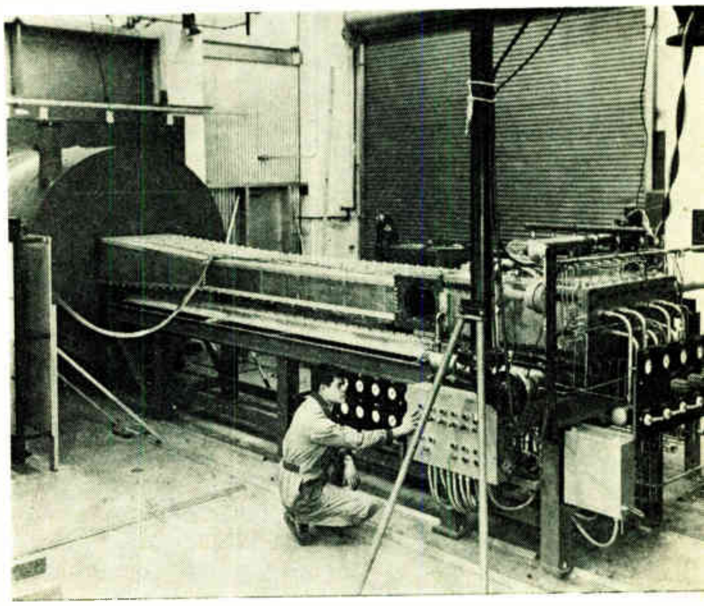


FIGURE 10. Results using an unstable resonator. Black line represents measured output power (of the order of 2 kW) whereas the colored line represents the theoretical far-field intensity distribution for an unstable resonator at 65 percent coupling operating in the lowest-order mode.

FIGURE 11. A recently constructed 14-kg/s gasdynamic device.



fluxes characteristic of a gasdynamic laser.

Under operating conditions similar to those for which 6 kW were produced in a multimode cavity, a power output of the order of 2 kW was achieved with the unstable resonator. Figure 10 shows IR scanner measurements. Also shown is the theoretical far-field intensity distribution for an unstable resonator of 65 percent coupling operating in the lowest-order mode. (The theoretical distribution has been multiplied by 0.2 to show it on the same scale as the output of the device.) This illustration indicates that the output radiance of the laser obtained under these operating conditions is approximately one sixth to one seventh that for pure lowest-order-mode operation, or, equivalently, about 2.5 times that for a diffraction-limited operation.

The mirrors used in these tests were copper and were operated in a heat-sink mode. Theoretical calculations indicate that significant distortion of these mirrors will take place during the run time and this distortion can lead to significant deviations from the ideal mode pattern.

In addition, in this device significant flow disturbances were present and these led to phase changes of a significant fraction of a wavelength across the beam cross section. Nozzle-array designs that eliminate or substantially reduce these flow disturbances have been developed. Also, water-cooled mirror structures that will not distort significantly under the heat loads of the gasdynamic laser have been developed. Although not conclusive, the results of these mode-control experiments on gasdynamic lasers seem to indicate that, with a uniform medium and with water-cooled mirrors, very near diffraction-limited performance of an unstable resonator can be achieved.

Finally, there are some fairly recent results to report about the large (approximately 14 kg/s) device shown in Fig. 11. This device, operated with CO as the fuel, has produced 60 kW of multimode power and 30 kW of near-diffraction-limited power in an unstable resonator, indicating the general scalability of these devices.

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Edward T. Gerry received the B.S. degree in physics from the College of William and Mary, the M.S. degree in engineering physics from Cornell University, and the Ph.D. degree from the Nuclear Engineering Department of the Massachusetts Institute of Technology. Much of his graduate research involved work with plasmas. At Avco Everett Research Laboratory, Everett, Mass., he previously was engaged in the development of high-temperature-plasma diagnostic techniques and in the study of dissipative processes in such plasmas. More recently, he has been studying population-inversion methods in gaseous-laser systems. The original work leading to the development of the CO_2 gasdynamic laser was led by Dr. Gerry. He is presently chairman of Avco's Laser Research Committee. Dr. Gerry is a member of the APS and the American Association for the Advancement of Science.

Integrated-circuit digital logic families

II—TTL devices

Although transistor–transistor logic is similar to diode–transistor logic in many respects, it is capable of yielding higher speeds and driving capability

Lane S. Garrett **Motorola Semiconductor Products Inc.**

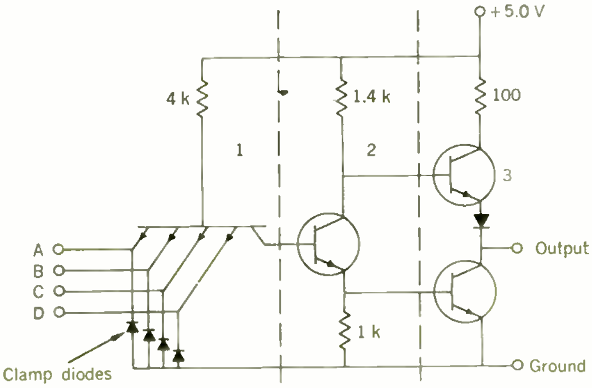
TTL devices offer the distinct advantages of many complex functions, compatibility with DTL, and adaptability to many designs, including some highly complex ones. Because of their wide availability in the market, they are extremely attractive from an applications and price standpoint. This second part of a three-part article describes their use in medium- and high-speed circuits and also covers Schottky TTL devices.

Transistor–transistor logic, or TTL, has become very popular in the past few years and several large families of devices are now available. Although circuit designs vary with manufacturers, in general they fall into two major categories—medium speed and high speed. Similar to diode–transistor logic and compatible with it for many applications, TTL may be thought of as a DTL modification that results in higher speed and driving capability. It is noted for better energy-noise immunity than that offered by DTL and is more effective for driving high-capacitance loads because of its low output impedance in both logic states.

A medium-speed TTL gate is shown schematically in Fig. 34. Nominal resistor values are given, but these values may differ slightly between manufacturers. To aid in the explanation of circuit operation, the gate has been divided into three sections, which will be explained separately, and then put together to form the NAND function, as shown in Fig. 35.

The input section of the gate (1) performs in a similar manner to DTL. The four clamp diodes tied to ground are reverse-biased for normal input voltages and therefore are neglected at this time. If one input or more is at a low level, current will flow through the 4-kΩ base

FIGURE 34. Typical medium-speed TTL circuit diagram.



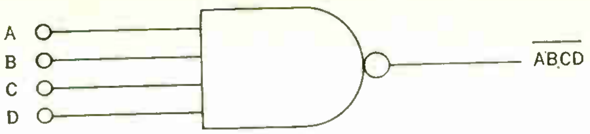
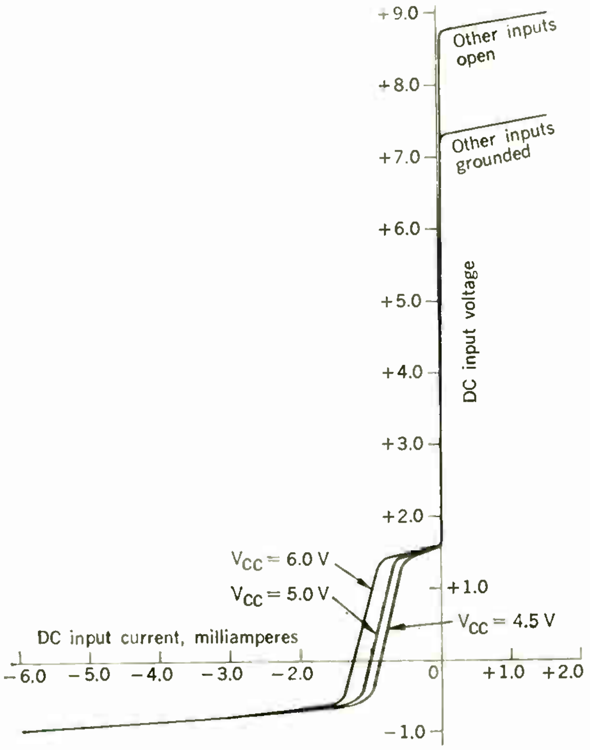


FIGURE 35. TTL basic gate, which performs the NAND logic function. The "implied AND" connection is not possible because of the "active pull-up."

FIGURE 36. Medium-speed TTL input characteristics. $V_{CC} = 4.5$, 5.0, and 6.0 volts; $T_A = 25°C$.



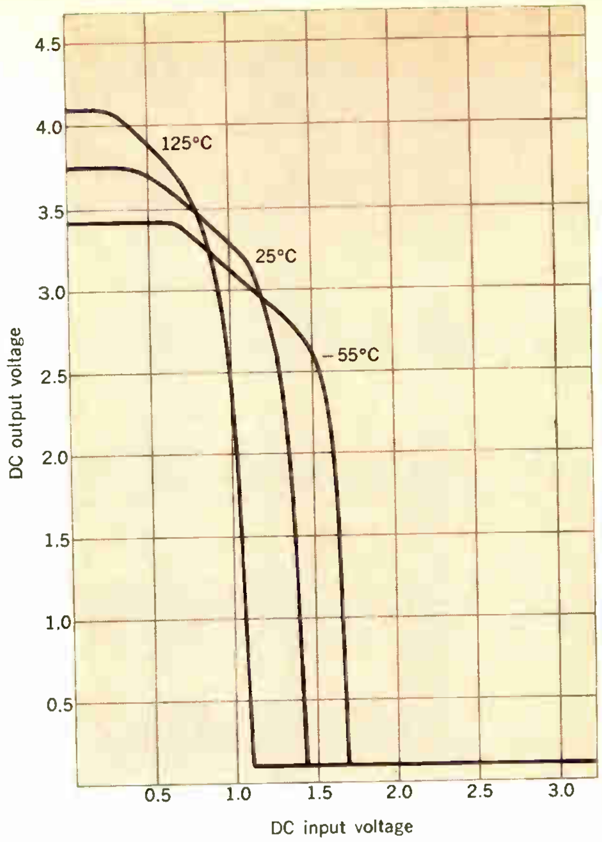


FIGURE 37. Medium-speed TTL transfer characteristics. Fanout = 0; $V_{CC} = 5.0$ volts; $T_A = -55°C$, 25°C, and 125°C.

resistor, giving a base voltage one diode drop above the lowest input voltage. The collector of the input transistor is then at a low level. Only when all the inputs are at a high level will there be current flowing from the base, through the collector, forward-biasing the base–collector junction. Then with all inputs high, the collector is also at a relatively high level. Thus we see that section 1 operates in the same manner as the input diode cluster of diode–transistor logic and performs the positive logic AND function.

Section 2 is what the "linear buff" calls a phase splitter. The emitter follows the base voltage (by a diode drop), whereas the collector-voltage change is out of phase with the base-voltage change. Looking at the collector and emitter voltages for high and low base-input levels we observe the following: With a low input voltage the transistor is off, yielding an emitter voltage close to ground and a collector voltage close to 5 volts. If the base is at a relatively high level, the transistor will be turned on. Since the resistance of the collector resistor is only slightly greater than that of the emitter resistor, and there are some losses in voltage gain through the multiemitter input transistor, we would expect an overall voltage gain of about unity at the collector of the phase splitter. Measured values of gain show this to be the case.

It should be noted that the emitter of the phase-splitter transistor is effectively clamped to the diode drop of the lower output transistor, allowing a maximum high-level input of two diode drops. Since the emitter is clamped and a generous amount of base drive is available through the 4-kΩ resistor, the phase-splitter transistor will saturate for a high-level input to the gate. Under these conditions the collector potential will be approximately 1 volt.

Let us now look at the output section (3) for the two states of the phase-splitter transistor. When the phase splitter is off, the bottom transistor of the "totem pole" receives no base drive, and therefore remains off, with a base potential of approximately 0 volt. The upper transistor receives drive through the 1.4-kΩ resistor and acts as an emitter follower. The output voltage is now about 3.5 volts (a base–emitter plus a diode drop below the 5-volt power supply).

Observing the circuit for the case in which the phase splitter is saturated, we see the opposite output condition. The lower transistor is saturated, whereas the upper transistor is turned off. The upper transistor input voltage must be greater than two diode drops plus a V_{sat} before it is turned on (approximately 1.7 volts). One should keep in mind that only about 1 volt is applied to the base for this case. The output diode is required to insure that the upper transistor remains off.

Putting all three sections of the gate together, we now have the NAND function; that is, only when all inputs are at a high level will the output be low.

Medium-speed TTL

Characteristic curves. The input, transfer, and output characteristic curves completely describe the dc parameters of the basic medium-speed TTL gate.

Some very interesting and descriptive characteristics should be noted. Observing the input characteristics given in Fig. 36, we see that typical input current for a high level is a rather low value but greater than that measured for a DTL circuit. Why is this? Looking back at the input circuitry we see that for a 3.5-volt input on the emitters, the base of the phase splitter remains at about 1 volt. The input transistor is biased for normal conduction; only the emitter and collector regions are interchanged. A transistor operating in this mode has an inverse β, which has been minimized through optimum device geometry and design. Typical values of inverse β are less than 0.02, giving high-level input currents of less than 20 μA.

If the input voltage is increased above 5.5 volts, a point will eventually be reached at which the input emitters break down into a low-impedance mode. An emitter–base junction has a "Zener" voltage that depends primarily upon the resistivity of the base diffusion. Since TTL is made with base diffusions normally around 200 ohms per square, junction breakdown occurs at about 6.8 volts. The total input breakdown voltage is the emitter–base breakdown plus the base–emitter drop of the input transistor plus the lowest potential that another emitter is tied to. For all inputs except one grounded, the breakdown at an input current of 1 mA is approximately 7.5 volts at 25°C—that is, a 6.8-volt Zener plus a 0.7-volt diode drop. Inasmuch as inputs can go below ground potential under transient conditions, and to account for processing and temperature variations, the maximum allowable input voltage is specified at 5.5 volts.

This specification also includes some guard band for the purpose of increasing the safety margin. If breakdown can ever occur in practice, input current must be limited to prevent "zapping" the gate. For this reason unused TTL inputs are *not* tied to the 5-volt supply, which may exhibit transients. It is recommended that unused inputs be tied to the supply through a 1-kΩ resistor, or be tied to the high-level output of an unused gate, or be tied together with an input that is already being used, thus increasing loading. Medium-speed and especially high-speed TTL inputs should not be left open because of the reduced noise immunity through pickup and the slower operating speeds caused by the unterminated input capacitance.

As can be seen from the portions to the left of the axis in Fig. 36, when the input voltage is brought more negative, input current will start to flow out of the emitter(s). This occurs at about 1.6 volts at room temperature. At an input of about 1.4 volts, most of the current through the 4-kΩ resistor has been switched from the collector and flows through the emitter(s). The amount of current is limited by the 4-kΩ base resistor. The equivalent circuit under these conditions is a forward-biased diode in series with a 4-kΩ resistor tied to V_{CC}. Note that the slope of all three curves for the different supply voltages is constant at 4 volts per milliampere, or 4 kΩ. The intercept on the voltage axis is approximately $V_{CC} = -0.75$ volt, which represents the equivalent of a diode drop.

Under transient switching conditions signal lines appear inductive, which (along with stray capacitance) causes lines to "ring." TTL switching speeds approach 1 volt per nanosecond, which complicates the problem. To reduce excessive "ringing," clamp diodes (Fig. 34) have been added to all inputs. The clamping action damps the ringing and prevents a negative voltage excursion in excess of one diode drop.

Without the input "clamp" diodes, the IC substrate is biased on, for negative excursions of 1 volt or greater. This prevents proper circuit operation in some instances and exhibits less effective damping for appreciable line lengths. The input characteristics determine the input specifications and provide useful information when interfacing TTL with discrete devices.

The transfer characteristics for a medium-speed TTL gate at three different temperatures are shown in Fig. 37. The high-level output supply voltage from the TTL gate is simply two diode drops below the power supply voltage. The transfer characteristics are taken for essentially no output loading, giving diode drops that are less than normal—about 0.6 volt. Note that the higher the temperature, the higher the output voltage, inasmuch as diode voltage drops decrease with increasing temperature.

If the input voltage is increased above ground, the output remains constant until the input approaches one diode drop above ground. At this point the curve exhibits a slope of approximately one to one. Referring to the diagram (Fig. 34), we see that when the input voltage approaches a diode drop above ground, the base of the phase splitter will see essentially the same voltage. As the input voltage increases further, the emitter of the phase splitter follows, causing most of the current to flow through the 1-kΩ resistor. The higher the input voltage, the higher the current through the 1-kΩ resistor until clamped by the base-to-emitter junction of the output transistor. Most of the current flowing through the 1-kΩ emitter resistor also flows through the collector resistor, causing a corresponding voltage drop. The voltage drop across the 1.4-kΩ collector resistor is reflected in a lower output voltage. The slope of the curve in this region is determined primarily by the ratio of the values of the collector resistors to the emitter resistors.

Although there are some losses in voltage gain through the input and output transistors, the slope can be used to determine this ratio with a fair degree of accuracy. The disadvantage of this property is that an input transient in this region will also appear in the output.

When an input voltage equal to the threshold of two diode drops is reached, the slope of the transfer characteristics changes and the output voltage drops rapidly, showing high voltage gain. For inputs greater than two diode drops ($\approx$1.5 volts at 25°C), the lower totem-pole output transistor is saturated.

Note how the break points and thresholds change with temperature. The change is usually between -3.5 and -4 mV/°C. The saturation voltage of TTL is only about 0.1 to 0.2 volt for light loads and remains relatively constant with supply-voltage variations, as can be seen in Fig 38.

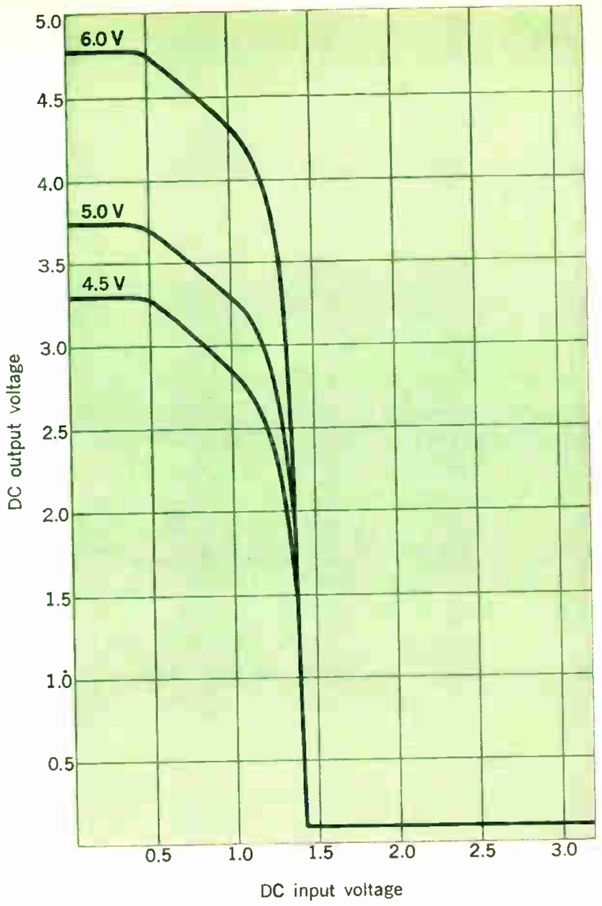


FIGURE 38. Medium-speed TTL transfer characteristics. V_{CC} = 4.5, 5.0, and 6.0 volts; T_A = 25°C.

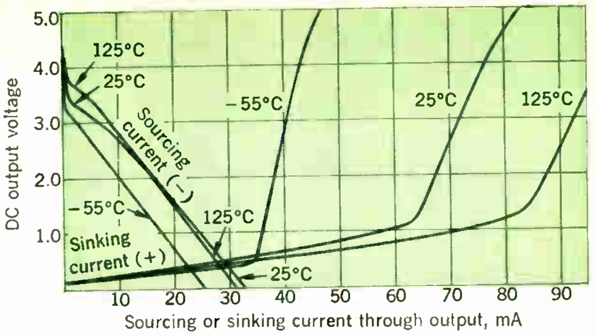


FIGURE 39. Medium-speed TTL output characteristics. V_{CC} = 5.0 volts; T_A = −55°C, 25°C, and 125°C.

Figure 39 illustrates the very useful TTL output characteristics at various temperatures. Notice that there are two sets of curves. When the totem-pole output is *sourcing* current to the output load, current flow is in the negative sense, although for convenience it is shown in the positive direction on the graph. Whenever a gate is charging load capacitance, the rise time or rate of charging is determined by the output impedance and the amount of capacitance. This brings out one of the big advantages of TTL. The low output impedance results in fast rise times for heavy loading.

Looking at the three sets of curves for the output acting as a source, we may obtain output impedance from the slope of the curve. Before the upper totem-pole transistor saturates, the output impedance is about 70 ohms. As more output current is drawn, the transistor saturates, limiting maximum output to that which can be supplied through the 100-ohm limiting resistor. The slope of the line is now approximately 100 ohms. This slope will vary, depending upon the resistor values in the circuit. Typical output impedance when sourcing 10 to 20 mA of current will vary from 75 to 125 ohms because of normal processing variations.

Notice that at −55°C the maximum source current is reduced. This reduction is caused by greater diode voltage drops. The maximum source current at 125°C is also limited below the value that might be expected because the diffused silicon resistors increase in value at high temperatures. An important advantage is that this low output impedance gives appreciably higher energy-noise immunity than would be expected with circuits that have passive pull-ups.

Looking at the characteristics for sinking current, we notice little variation with temperature for normal loads of around 5 to 10 milliamperes. If appreciably more current is forced into the output, a break point is reached, in the characteristics, where the output transistor is pulled out of saturation. This break point can be used to determine the current gain of the output device. Note that transistor β decreases rapidly with decreasing temperature. Reduced β limits the maximum fanout available at −55°C. Note that over a limited temperature range (that is, 0 to 75°C), the transistor can get by with lower room-temperature β. Fanout is simply the ratio of worst-case output current drive capabilities divided by the maximum current that can be drawn from a gate input.

Figure 40 gives a set of curves similar to those shown in Fig. 39, except that the supply voltage instead of temperature is varied. Note that both current sourcing and sinking are roughly proportional to supply voltage, as might be expected from the circuit design. Current-sourcing ability is determined by a resistor in series with the supply, and current-sinking ability is transistor β times base current. The base current is also determined by a resistor in series with the supply voltage. It is seen that the worst-case fanout occurs at low temperature and low supply voltage. The nominal 5-volt supply represents a tradeoff between performance and power dissipation.

The input, transfer, and the output characteristics of the TTL design determine the dc properties and specifications of the family. This set of characteristic curves was developed for a typical gate, which more or less falls in the center of the normal distribution of medium-speed TTL.

AC operation and characteristics. TTL is the fastest form of saturated logic. Let us reexamine the circuit (Fig. 34) and determine some of the reasons for this. First, consider the case where all the inputs are high and then one of the inputs is brought to a low level, turning the gate off. The time delay for this action is commonly called turn-off time, which represents the amount of time after the input goes through threshold that the output turns off or goes above threshold.

Observing the schematic diagram of Fig. 34 we see

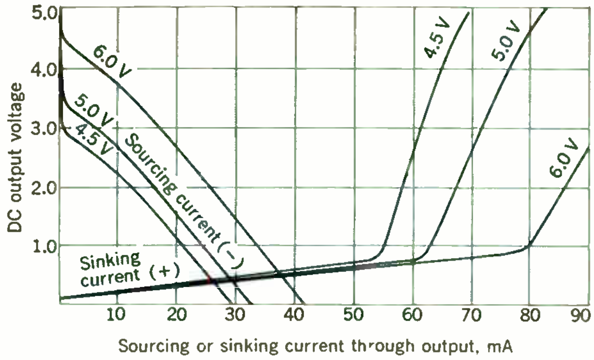


FIGURE 40. Medium-speed TTL output characteristics. V_{CC} = 4.5, 5.0, and 6.0 volts; T_A = 25°C.

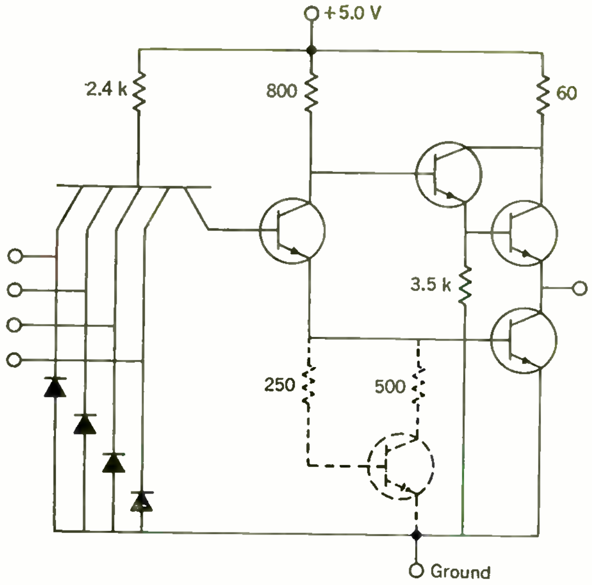


FIGURE 41. Typical high-speed TTL circuit diagram.

that first the input transistor must be turned on. Because of transistor action, charge is rapidly pulled from the base of the phase-splitter transistor. Therefore the TTL input is faster than the DTL type of input, which has no gain.

The phase splitter turns off fairly rapidly, turning the top of the totem pole on. At the same time, the bottom transistor in the totem pole is turning off as charge flows to ground through the 1-kΩ base pull-down resistor. The bottom transistor turns off a little later than the upper transistor turns on. This results in a brief low impedance, which is seen across the power supply, causing a small surge of current. This current surge or spike is about 15 milliamperes in amplitude for a few nanoseconds. As frequency is increased, the power-supply current also increases as the integral of the current spikes.

The resulting increase in power dissipation is relatively small for low frequencies, and works out to be approximately 0.30 to 0.35 mW/MHz. This factor could be improved by lowering the value of the 1-kΩ resistor, which requires higher-β transistors and/or a higher value of the 1.4-kΩ resistor. Thus the tradeoffs are in tighter processing specifications and increased dc power dissipation. With good layout techniques and frequent power supply bypassing, the current spike, or "glitch," is a very minor problem for normal system speeds.

We will now look at the gate under turn-on conditions. This occurs when all the inputs are brought to a high level. The input is now slower, since transistor action does not take place, but it should be noted that the input transistor was not heavily saturated and, since it is gold-doped, the response time is low. The phase splitter has good base drive and turns on rapidly. Very good base drive is now presented to the bottom transistor in the totem pole, turning it on rapidly. The upper totem-pole transistor does not saturate for normal loads, and therefore has negligible stored charge. A low-impedance pull-down is provided by the phase splitter, causing the upper transistor to turn off rapidly. Current spiking is usually negligible because of the rapid turn-off of the upper transistor.

The sums of the input, phase-splitter, and output delays for both the turn-on and turn-off times are similar. Therefore, propagation delays are optimized by this circuit design, giving almost identical turn-off and turn-on delays. Propagation delays are about 10 to 14 ns for this circuit.

Some circuit designs have the standoff diode in the base lead of the upper transistor. This results in slightly faster output rise time and lower output impedance. The writer prefers the standoff diode in the output, because of smaller current glitches and the resulting lower ac power dissipation. The diode in the base prevents rapid turn-off, especially at higher frequencies and temperatures, where the upper transistor may saturate as a result of the load current that is required to charge the inevitable line capacitance. This, unfortunately, results in the creation of a turn-off current spike that may, under unfavorable conditions, be even greater than the turn-on glitch.

Typical parameters of medium-speed TTL are as follows:

Power dissipation ≈ 12 mW per gate
Rise time ≈ 2.5 ns, fall time ≈ 1.5 ns (measured between 1-volt and 2-volt intervals)
Maximum clock rate = 20 MHz
Propagation delay ≈ 12 ns
Fanout ≈ 10
Threshold ≈ +1.4 volts
V_{CC} = +5 volts ± 10%
Z_{in} (high) ≈ 400 kΩ
Z_{in} (low) ≈ 4 kΩ
Z_o (high) ≈ 70 ohms
Z_o (low) ≈ 10 ohms (R_{sat})
V_{OH} (nominal) = 3.5 volts
V_{OL} (nominal) = 0.2 volt
$V_{IH(max)}$ = +5.5 volts
$V_{IL(min)}$ = −0.5 volt

High-speed TTL

The basic TTL circuit is easily modified to produce higher speed. The speed of a saturated logic circuit depends largely on two factors: storage time and RC time constants. In high-speed TTL, gold doping and lower base pull-down impedances effectively reduce storage time. Lower values of pull-up resistors also significantly reduce *RC* time constants, allowing for more rapid switching times. One of the more advanced circuit designs is shown in Fig. 41.

Of course, the tradeoff has been in higher power dissipation. The typical input current is now 50 to 60

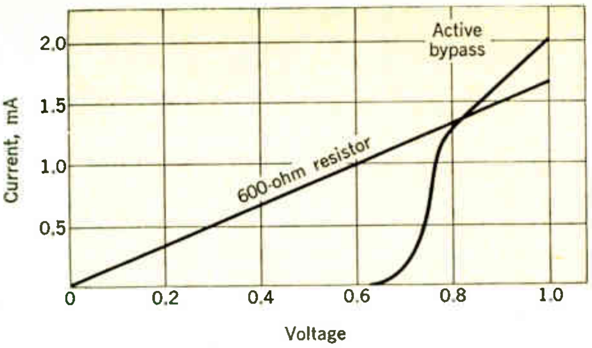
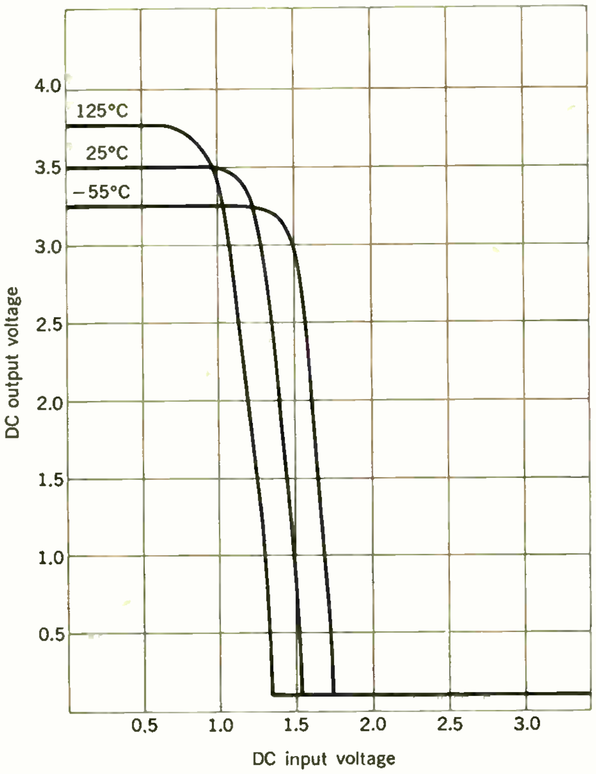


FIGURE 42. Impedance plot of "active base pull-down" as compared with that of a 600-ohm resistor, at 25°C. Note the nonlinear impedance of the active circuit. Negligible current is "sinked" for voltages of less than one diode voltage drop.

FIGURE 43. High-speed TTL transfer characteristics. Fanout = 1; V_{CC} = 5.0 volts; T_A = −55°C, 25°C, and 125°C.



percent greater than that for medium-speed TTL. When all inputs go high, capacitance is charged more rapidly, allowing rapid turn-on of the phase-splitter transistor. The input characteristics are the same as for regular TTL except for the higher current that flows through the input emitters.

The phase splitter performs the same function and produces approximately the same voltage levels as before. Internal impedance levels have also been reduced to about 60 percent of their previous values, thus giving a corresponding reduction in *RC* time constants. The lower totem-pole transistor is basically the same except that the lower base-drive impedance allows higher current-sinking capabilities.

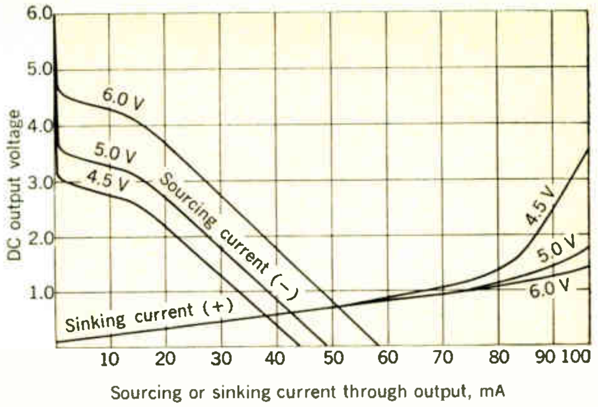


FIGURE 44. High-speed TTL output characteristics. V_{CC} = 4.5, 5.0, and 6.0 volts; T_A = 25°C.

There are two major circuit differences other than reduced impedances:

1. The Darlington active pull-up has a single collector resistor, which simplifies the design and effectively reduces saturation. Therefore the ac power dissipation is reduced.

2. The active base pull-down for the lower totem-pole transistor minimizes temperature effects and gives the gate a "square" transfer characteristic.

In the active pull-up, voltage levels are approximately the same, with the high output level two diode drops below the supply voltage and the upper part of the totem pole still requiring an input in excess of two diode drops plus a V_{sat} before turning on. The high-level output is obtained through two transistors acting as emitter followers—that is, a Darlington connection. Therefore, the high-level output impedance is very low, of the order of 10 ohms. This results in a higher output voltage for a given load current, until current is limited by the collector resistor. The Darlington design keeps the upper totem-pole output transistor from saturating, since its collector–emitter voltage is clamped to a minimum of one diode drop plus the V_{sat} of the driver transistor. This configuration results in a significant reduction of the gate turn-on current glitch, since the Darlington turns off very rapidly.

The second major circuit difference is noted in the pull-down network for the lower totem-pole transistor. This network, which looks like an RTL circuit, is shown in dashed lines in Fig. 41. Since impedance across the device is nonlinear, some interesting properties are provided. At voltages below one diode drop the impedance is quite high. At one diode drop the active pull-down has approximately the same impedance as a 600-ohm resistor, but the impedance drops to effectively 500 ohms for higher input voltages. Figure 42 illustrates the impedance characteristics of the active pull-down network as compared with one employing a nominal 600-ohm resistor.

At room temperature the active network helps prevent excessive saturation of the lower totem-pole transistor and allows far more rapid turn-off, since the active pull-down remains at a low impedance value for a few nanoseconds. Another advantage is apparent during turn-on, when the active pull-down diverts initial turn-on

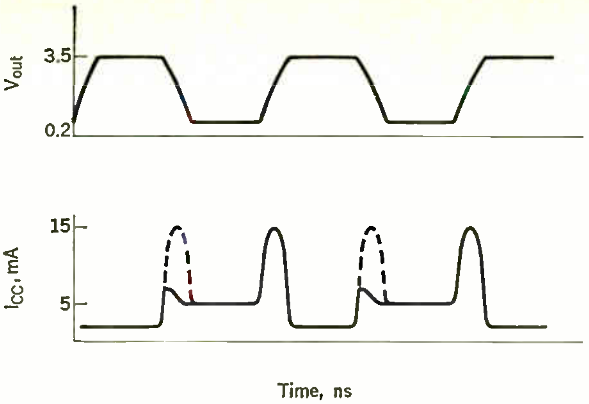


FIGURE 45. TTL voltage and current waveforms. The amplitude and pulse width of the current spike vary with circuit design and the amount of loading. The dashed line represents the turn-on spike that is present in some high-speed designs.

current directly to the base of the output device and thus provides superior base drive.

The biggest advantages of the active pull-down are evident with regard to temperature variations. At elevated temperature, where β is higher and the threshold of the output device is lower, turn-off delay is prominent. Diffused resistors increase in value at high temperature, complicating the problem. The threshold of the active pull-down tracks the output device threshold, thus providing lower impedance at high temperature. The ever-present Miller capacitance between the collector and base of the output device speeds turn-off in conjunction with the active pull-down. As the collector voltage starts to rise, this change is fed back to the base, thus trying to increase base voltage. This effectively causes the active pull-down to sink additional current, which in turn speeds device turn-off. Therefore, degradation of turn-off time with increasing temperature is less apparent than with other pull-down designs. At low temperature the active bypass network has a higher impedance than the equivalent 600-ohm resistor, and thus additional current is diverted into the output device, which in turn increases the current-sinking capabilities of the output.

Since the active pull-down improves characteristics, both easier processing and improved specifications become possible.

Perhaps the most notable effect of this design is in the change in transfer characteristics. Since the active pull-down impedance is very high for low input voltages to the gate, no current is drawn through the phase-splitter transistor until an input voltage of two diode drops is approached. The result is the "square" transfer characteristics shown in Fig. 43.

The characteristics are very similar to those of DTL circuitry except for a reduced high-level output voltage. At room temperature, inputs of up to 1 volt will not start to change the output voltage. It should be noted that this set of curves is taken for a fanout of 1, resulting in a lower high-level output voltage than shown previously. (Compare these curves with those shown for medium-speed TTL in Fig. 37.)

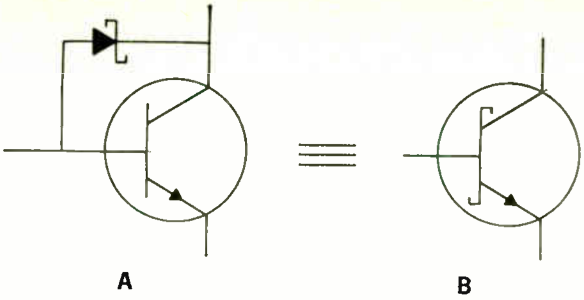


FIGURE 46. A—Transistor with a Schottky diode clamp. B—Monolithic Schottky transistor.

The high-speed TTL transfer characteristics provide much better isolation between gate inputs and outputs for ground line noise spikes, which are common in TTL systems.

Since internal impedances are lower, the output can drive more current into external capacitance and sink higher current from the load. Output characteristics are shown in Fig. 44.

Typical high-speed TTL characteristics may be listed as follows:

Power dissipation (gate) = 22 mW
Power dissipation (flip-flop) = 50–80 mW
Average propagation delay (gate) = 6 ns
Average propagation delay (flip-flop) = 13 ns
Maximum flip-flop clock frequency = 50 MHz
Temperature range = 0°C to 75°C or −55°C to 125°C
Supply voltage = 4.5 to 5.5 volts
Noise immunity (25°C) = 400 mV
Z_{in} (high) ≈ 400 kΩ Z_{in} (low) ≈ 2.4 kΩ
Z_o (high) ≈ 10 ohms Z_o (low) ≈ 10 ohms
Fanout = 10   Threshold ≈ 1.5 volts
Rise time ≈ 1 ns   Fall time ≈ 1.3 ns

AC power considerations in saturating TTL

Because transistor turn-off times are normally longer than turn-on times, a short power-supply current glitch occurs when a TTL gate turns off. A turn-on current glitch of various magnitudes may also occur, depending upon circuit design and the amount of output loading. This ac power factor is normally not a systems concern since only a few devices are being switched at a given time. The ac power dissipation does, however, limit the maximum operating frequency of TTL. Some designs show double the nominal power dissipation at 30 MHz. Plots of power-supply current and changing output voltage are given in Fig. 45.

Current spiking increases with loading and increased temperature (which increases β and thus the storage time). Although this parameter is not specified, it should be taken into consideration, especially when TTL is being pushed to its limits.

Schottky TTL

Gold doping is effective in eliminating most delay caused by storage time, but is a cumbersome process that normally leads to some yield loss, especially with shallow-junction high-performance transistors. If a transistor can be kept out of the saturation region, storage time is eliminated without the expense involved in gold doping.

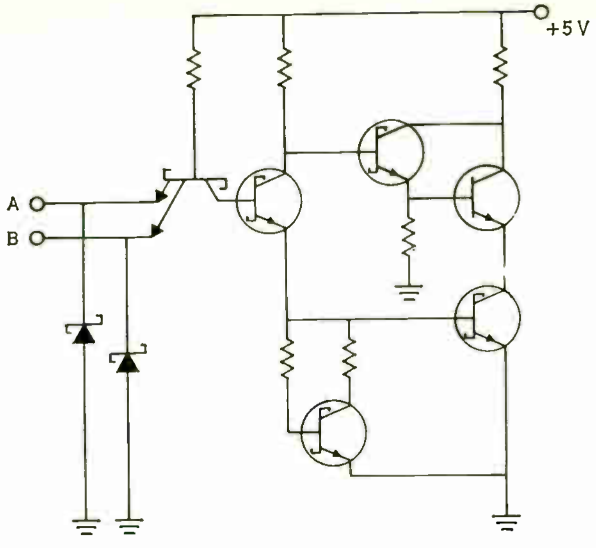


FIGURE 47. Schematic diagram of "active pull-down" TTL circuit employing Schottky-diode clamping technique.

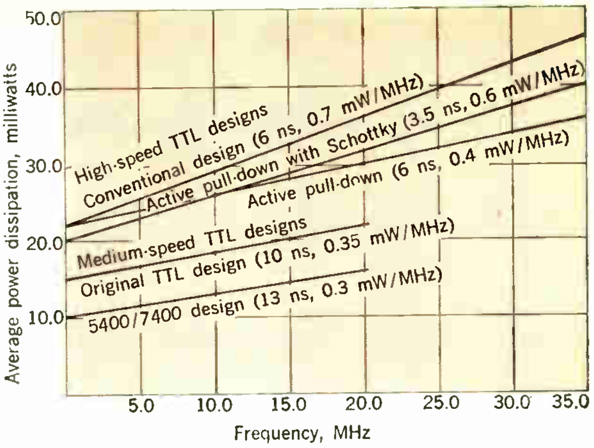


FIGURE 48. Average TTL power dissipation vs. frequency for typical gate, with 50 percent duty cycle.

Two basic techniques are commonly employed. The type of circuit design used in current-mode or emitter-coupled logic prevents saturation. Emitter-coupled logic will be discussed next month. The second basic technique involves clamping the base–collector junction to a value less than a saturation voltage. This is easily done with discrete devices by the use of a germanium diode (with a low forward-voltage drop) to shunt current around the base–collector diode before a saturation voltage is reached.

With IC technology, Schottky diodes can perform the same function and fit easily into present processing capabilities. The symbol for a Schottky-clamped transistor is illustrated in Fig. 46. Using monolithic technology, the Schottky diode is easily built within the same collector isolation region as the transistor. This then is commonly referred to as a Schottky-clamped transistor, or a Schottky transistor.

The active pull-down TTL circuit is easily adapted to the Schottky-diode clamping technique. The Schottky diode breaks down with a forward bias of about 0.4 volt. The slope of the forward-breakdown curve is a function of the resistive component of the diode. The circuit is illustrated schematically in Fig. 47.

Note that the input clamp diodes are Schottky diodes, and therefore exhibit a lower breakdown voltage than would a normal silicon p-n junction. Thus clamping is more effective by about 20 to 30 percent. The input transistor has the advantage of fast turn-off, but the disadvantage of a lower base–collector breakdown voltage caused by the Schottky. The gate input threshold is therefore lower than in a conventional TTL gate. The "active pull-down" functions as previously mentioned and helps to "square up" the transfer characteristics. As previously stated, the lower transistor of the Darlington does not saturate and therefore does not require a Schottky clamp.

The Schottkys have the advantage of eliminating storage time without gold doping, but the disadvantage of adding appreciable capacitance to the circuit. To improve the circuit speed significantly, transistors with high f_T and low capacitance are required. The Schottky diodes also permit transistors with higher β—a desirable feature from a circuit standpoint. Higher β does not significantly increase storage time, since the transistors are not in saturation. The primary delays of the Schottky clamped circuit are dependent upon *RC* time constants, resulting in slower rise and fall times in comparison with the propagation delay.

The low output level is more positive than the V_{sat} of standard TTL, due to the Schottky clamp. The higher V_{OL} level and lower threshold both decrease the noise margin for ground line noise, which is usually the most critical in a system. Schottky transistor–transistor logic exhibits approximately 8 mW of power-noise immunity whereas the conventional TTL design results in about 13 mW of power-noise immunity, looking into the ground lead.

Typical parameters of Schottky TTL are listed for reference:

Temperature range = 0°C to 70°C
Power dissipation per gate ≈ 20 mW
Maximum flip-flop clock frequency ≈ 100 MHz
Supply voltage = 4.75 to 5.25 volts
Average propagation delay (low to high) ≈ 3.0 ns
Average propagation delay (high to low) ≈ 4.0 ns
Specified noise immunity (25°C) = 300 mV
Threshold region ≈ 1.2 to 1.5 volts
Z_o (high level) = 70 ohms (high current), 10 ohms (low current)
Z_{in} (low level) ≈ 3 kΩ
Z_o (low level) ≈ 10 ohms
Fanout = 10
V_{OH} ≈ 3.5 volts
Rise time ≈ 4.0 ns
Fall time ≈ 3.0 ns

Because of unequal turn-on and turn-off times in the circuit and the inherent chip capacitances, Schottky TTL also exhibits increasing power dissipation with frequency. Figure 48 compares the ac power dissipation vs. frequency of operation for five common types of TTL design.

Layout guidelines

In view of the high performance of TTL logic, care must be observed in the physical layout of logic cards and the interconnecting wiring. There are a few general

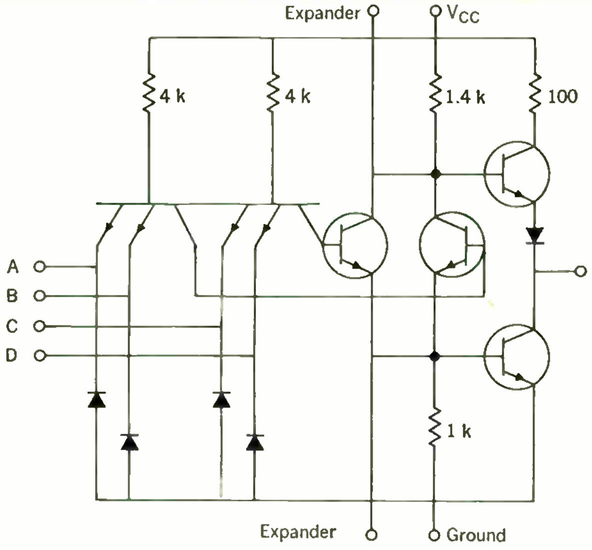


FIGURE 49. TTL gate with A-O-I function.

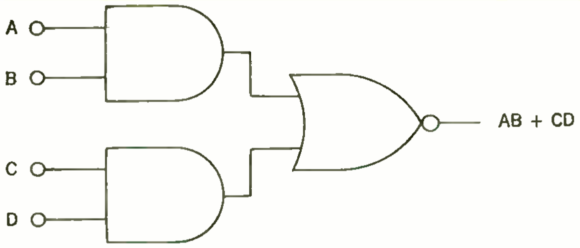
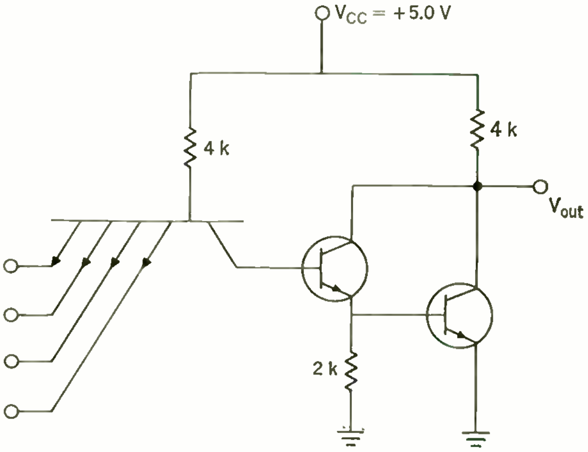


FIGURE 50. Equivalent A-O-I logic diagram.

FIGURE 51. Low-level TTL gate. Propagation delay = 5 ns; power dissipation = 7 mW.



guidelines that should be followed to prevent problems caused by the fast switching rates of TTL. Switching rates are of the order of 10^7 amperes per second and 10^8 volts per second, and coupling between parallel signal paths by mutual inductance is directly proportional to the rate of change of current in the lines. Therefore, the higher the *di/dt* the higher the induced noise voltage. Signal lines also have mutual capacitance, which permits a transfer of energy proportional to the rate of change of voltage between the lines.

In low-impedance systems most of the noise energy is transferred through inductive coupling, whereas mutual capacitance dominates in high-impedance systems. False signals that are induced in adjacent signal lines are referred to as crosstalk. Therefore, it is extremely important for a user not to tie together, or even run parallel, the various signal leads found in a system. In a large system where various logic cards in bays of logic are interconnected in a back plane, random or point-to-point wiring is recommended.

Because of the switching transients of TTL, a low power-supply impedance for high frequencies must be assured. Recommendations are that a 0.1-μF to 1-μF bypass capacitor be used where the supply and ground connections enter the printed circuit board. A 0.01-μF disk ceramic bypass capacitor is recommended for every four to eight packages on the board. The amount of bypassing required varies with the board design, the particular TTL family used, and the amount of capacitance being driven by the TTL outputs. A maximum amount of copper should be left on the printed circuit board, since mutual capacitance between copper planes effectively reduces the high-frequency components of noise.

Ideally, the printed circuit board should contain a ground plane sandwiched between signal planes. High-speed TTL requires more bypassing, especially for the high-frequency components of noise. Also, if the TTL must drive a high-capacitance load, between 50 and 500 pF, additional bypassing is recommended to provide the necessary charge for the load when the TTL output switches high. If adequate bypassing is not provided, the power-supply voltage temporarily drops because of the inductance of the distribution system. If this drop is excessive, noise immunity suffers and system errors are allowed.

Signal fidelity is often poor as the result of mismatched impedances in the wiring interconnections. TTL output impedances are as low as 10 ohms, whereas signal line impedances vary between 50 and 150 ohms and TTL input impedances go above 100 000 ohms. The resultant signal reflections cause waveform overshoot, undershoot, and ringing, a problem that increases with line length and capacitive loading. For lines longer than about 0.6 meter, especially with capacitive loads in excess of 50 pF, twisted-pair transmission is recommended. An unbalanced twisted-paired line is obtained by taking an extra wire and twisting it around the signal lead and returning the wire to ground. This has two beneficial results: First, the signal lead characteristic impedance is lowered; second, the external field caused by switching transients is greatly reduced. For lines longer than about 1.5 meters, TTL line driver and receiver circuits should be used. These circuits have been designed to match impedances and to give good common-mode noise immunity.

Is there a method whereby we can increase the logic flexibility of the basic TTL gate? DTL logic offers the option of tying gate outputs together, thereby providing the "implied AND" function, as was demonstrated previously.

If we substitute TTL gates for DTL, we have a problem. Since one of the gates can be on and the other one off, at the same time, we have the active pull-up of one gate working against the saturated output of the other gate. The low level usually predominates but, due to processing, variations cannot be guaranteed. Also, power dissipation is increased by 150 to 200 mW because of the 30 or 40 mA drawn from the active pull-up. For these reasons, TTL outputs should not be tied together. The same extra level of logic obtained by tying DTL outputs together can be obtained with TTL by modifying the basic gate design slightly. The schematic diagram shown in Fig. 49 illustrates this modification. Note that there are two phase-splitter transistors tied back to back. If either one is turned on, the gate output will go low. There are two multiemitter input transistors or two input clusters. If inputs A and B are high, the respective phase-splitter transistor turns on (or if C and D are high, the other phase splitter turns on), causing the gate output to be low. Summarizing, we can say that if A and B are high or if B and C are high, the gate output will *not* be high. This implements the AND–OR–INVERT function, shown in Fig. 50, which generates a logic function equivalent to the implied AND of DTL. The advantages of the A-O-I function are that an additional level of logic is obtained without increased power dissipation and with only a minor increase in propagation delay. Additional input clusters can be added through the use of two expander terminals. Since the expander nodes are of relatively high impedance, care should be exercised in adding expanders. The additional capacitance will slow down the gate, and noise can be induced more easily than through the regular inputs.

Other possible circuit modifications aid in the fabrication of medium-scale and large-scale integrated circuits. The most common modification is that of the low-level TTL gate shown in Fig. 51.

Low-level TTL gate

The input characteristics of the low-level gate are the same as those of a medium-speed TTL gate with about 1 milliampere of input current, but there the resemblance ends. There is no phase splitter and no active pull-up. The two transistors in the output are connected in a Darlington configuration. Turn-on is rapid, because of the gain of the Darlington and the fact that there is no need to remove charge from an active pull-up. Note that when the output is turned on, the output voltage is not V_{sat}. The predriver transistor has an emitter that is clamped to one diode drop above ground. Saturation occurs in the predriver transistor, giving a collector-to-emitter voltage of a few tenths of a volt. The output voltage is then a diode drop plus a V_{sat}, or about 1 volt. The disadvantage here is that the gate cannot meet normal TTL output specifications and the low-level output is close to a threshold voltage. These disadvantages become negligible if the gate is used internal to a complex function or logic array. The advantages are several. First, since few components are used, only a small area is required. The output transistor (which does not saturate) can turn off rapidly, thereby giving high-speed operation. A passive pull-up permits the "implied AND" connection, which can replace the more complex A-O-I configuration. In short, this gate provides the best speed–power product and logic flexibility found in TTL. On-the-chip delays of 5 ns, as well as 7 mW of power dissipation, are common.

The low-level gate interfaces well with the square transfer characteristics of non-Schottky TTL with an active pull-down, since a 1-volt input gives a firm high level out of the gate.

Conclusion

TTL has found such a wide area of application in different designs that it is easier to list those areas in which transistor–transistor logic is not recommended than those in which it is recommended.

TTL areas of application

TTL is employed almost anywhere except in

1. Very-low-power applications, where CMOS is preferred.
2. High-noise areas, where HTL is preferred.
3. Low-cost, low-complexity areas, where RTL is preferred.
4. High-speed areas, where ECL is preferred.
5. Low-speed, low-cost, low-complexity areas, where DTL is preferred.

Although TTL is used very widely, it still has a number of faults.

TTL disadvantages

1. TTL has high values of di/dt and dv/dt, and therefore more care is required in the layout and mechanical design of systems.
2. TTL generates "glitches" when switching, and thus additional capacitors are required for bypassing.
3. The "implied AND" function is not available by tying outputs together, as in DTL.

TTL trends are favorable into the mid-70s. New product introductions will force a long life cycle for the family. The unusually stiff competition will keep pricing at rock bottom and tend to set industry pricing trends in other families. Much of the product that is being developed in the LSI and solid-state memory areas will be directly compatible with TTL. The reasons for TTL strength in the market are summed up in the listing that follows.

TTL advantages

1. A large number of different devices and complex functions are available.
2. TTL is compatible with DTL specifications.
3. A-O-I gates provide an extra level of logic without increased power dissipation.
4. Low output impedance results in superior drive capability.
5. TTL has very good immunity to externally generated noise.
6. TTL results in a better system speed–power product than is obtainable with other saturated forms of logic.
7. High-speed capabilities allow more work to be accomplished in a given amount of time.
8. Multiple sources and extensive competition have resulted in low prices.
9. Compatible specifications allow the mixing of various families for optimum designs.
10. The large number of additional new products being planned promises a long life cycle for TTL.

Solid-state switching for aircraft electric systems

The entire concept of aircraft electric systems must be revised when designing for solid-state control. Not only must the design protect the wiring, it must protect itself and operate with high efficiency

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An aircraft electric system designed around a solid-state approach offers many potential advantages over an electromechanical counterpart. These include higher reliability, longer life, more ruggedness, more versatility, and better compatibility. To achieve these advantages, however, it is not merely sufficient to replace electromechanical components with their solid-state equivalents. Here is one approach that has been tested in the laboratory and in aircraft during the past ten years—with success. Included is a report on an advanced system undergoing evaluation.

The trend in advanced high-performance aircraft is to more sophisticated missions, which require more complex electric and electronic systems. This complexity has created an exponentially increasing quantity of switches, circuit breakers, and wires. Moreover, complex digital avionics systems require clean (transient-free) electric power—emphasizing a need for electromagnetic and interface compatibility between signal systems and digital computers.

The increase in complexity and compatibility requirements cannot be compensated or fully met by existing electromechanical devices that are simply the product of (two decades of) miniaturization. This miniaturization, without a comparable reduction in system voltage, has resulted in such high electrical-stress levels that misapplication of the devices has become all too easy. Major advances must therefore be made to optimize future aircraft systems—and these advances cannot be achieved by using conventional approaches and techniques.

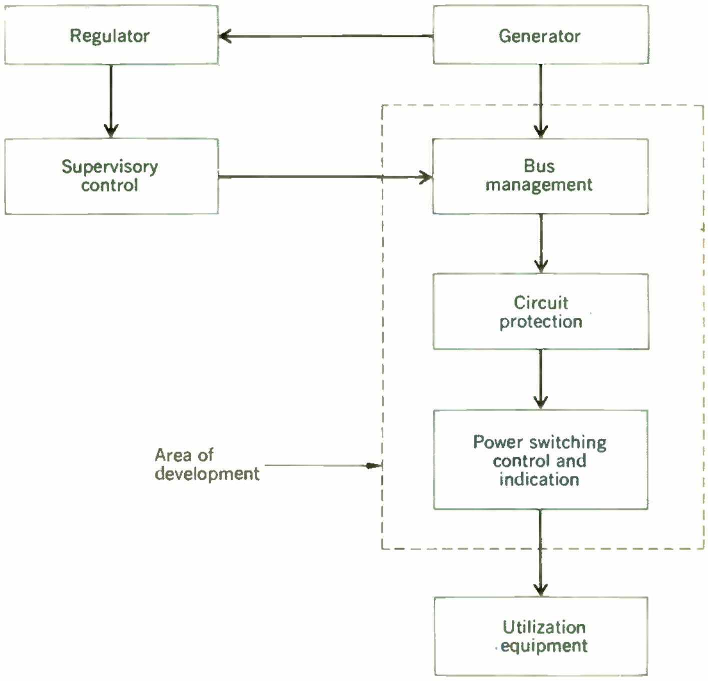
A new approach is necessary—one that will simplify circuitry, combine functions, separate signal- and power-switching requirements, and eliminate unreliable features to control switching and protect circuits and devices.

Taking a cue from other applications

Very rapid advances have been made in the electronics field, especially in digital computers, through the development and application of solid-state switching techniques that utilize semiconductor devices. It is evident that success might be achieved by applying like techniques to aircraft electric systems that gather and display information and distribute the flow of power to equipment. The application of such technology to aircraft electric-distribution systems, however, has been slow to receive approbation, because of the applications approaches that generally have been made to date.

Figure 1 is a block diagram of an aircraft electric system showing the area of primary concern of this article. Figure 2, representative of present-day electric systems, is included to highlight the fact that logic functions are performed at the power level. Such present-day systems are inherently heavy, require complex harness routing, and are growing larger and heavier with each new requirement. These systems also require large quanti-

FIGURE 1. Block diagram of an aircraft's electric system.



ties of power-handling, electromechanical devices that are subject to wear, create large voltage transients, have limited cycle life, and have low cycling rates. Besides, they do not lend themselves to automated checkout and thus create complex checkout–maintenance problems.

A number of solid-state devices (relays and circuit breakers) have been placed on the market with the idea of providing a solid-state device to replace an electromechanical one on a part-for-part basis. This tactic has some obvious drawbacks considering the voltage level at which logic functions are performed in most aircraft electric control circuits. Because of the voltage-drop and power-dissipation characteristics of semiconductor devices (even when operated in deep saturation), the approach produces a very inefficient system and makes it impossible to meet the voltage-drop requirements of MIL-W-5088 (Aircraft Electric Distribution System Specification) in many circuits. It is possibly for this reason that many designers have concluded that solid-state switching for power-distribution systems is not practical. Were high-voltage drop an insurmountable impediment, their conclusion would be justified. However, semiconductor devices have the advantages of high reliability, long life, and small size. If properly applied, they could provide the urgently needed improvements in aircraft electric distribution systems.

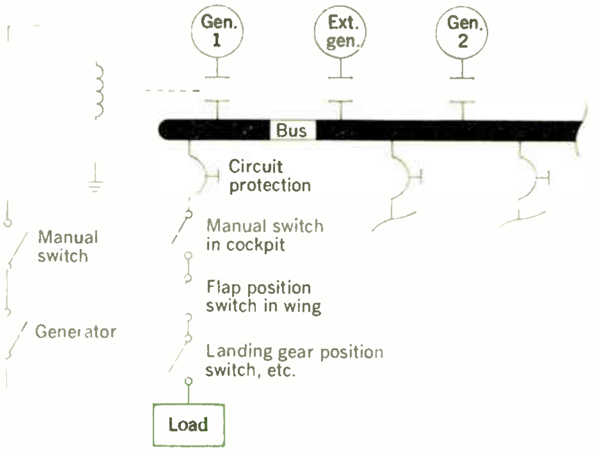
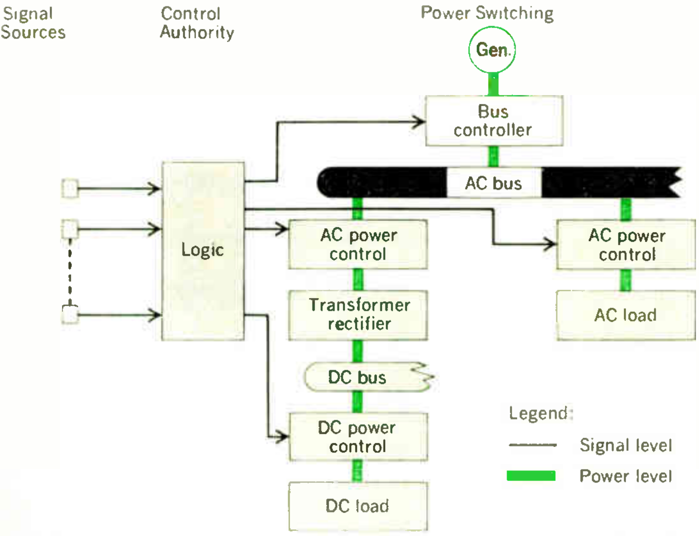


FIGURE 2. Present-day electric system.

FIGURE 3. Solid-state electric-system concept.



The number of solid-state components that can be connected in series while complying with MIL-W-5088, or allowing high power-control efficiency, is limited by the voltage drop through the solid-state devices (typically 0.5 to 1.5 volts per device). Ordinarily, aircraft power-control circuits require several relay contacts in series. The use of solid-state relays in such circuits, therefore, is not permissible. Nor is it practicable to combine solid-state and electromechanical components since electromechanical circuit breakers cannot protect solid-state switches. (Admittedly, the purpose of circuit breakers in present-day airplane electric systems primarily is to protect the wiring; but solid-state relays, flashers, timers, and other such components are more likely to be destroyed as a result of overload or fault condition than their electromechanical counterparts when operating under the same conditions.)

A new approach

The overall effort to develop an advanced electric system for aircraft has been given several names, among which are: contactless switching, solid-state switching, and SOSTEL (solid-state electric logic). All represent an application of semiconductor technology to the management and control of aircraft electric systems. Our studies centered on separating power switching from signal switching, and on switching power through a minimum number of semiconductor devices. This procedure minimizes the voltage drop between the source of power and the equipment supplied. More important, it provides efficient power control since power dissipation is held to a minimum. (Also, low power dissipation necessitates less sinking and, therefore, reduces size and weight requirements.) In addition, the separation of power from signal switching provides high system efficiency and makes it possible to meet the voltage-drop requirements of MIL-W-5088. All factors considered, the separation concept makes maximum use of semiconductors' advantages and minimizes their disadvantages.

The solid-state electric system shown in Fig. 3 represents a basic model of its sort and is composed of three building blocks: (1) the digital signal sources (such as temperature and pressure transducers); (2) the control logic (including bus monitoring and built-in test); and (3) power controllers (bus-switching and load controllers).

The source signals are fed into the control-logic unit. There, they are correlated in a prescribed manner to generate a signal that controls the power controllers. The logic switching is performed by standard integrated-circuit NAND/NOR gates that provide maximum reliability with minimum space and weight.

The fanout capability ordinarily provided by multipole switches and relays in an electromechanical system is now provided by integrated circuits and is performed at the signal rather than the power level. This technique considerably reduces the number of wires needed to gather intelligence from the various controlling functions. And since the intelligence is gathered at the signal level, what wire there is may be sized small. Power flow from source to bus to load is controlled by power controllers.

This sort of system is so flexible that a designer can incorporate an automatic bus-monitoring system to

I. Comparison of electric systems (A-7 aircraft)

	System		Reduction, percent
	Conventional	Solid State	
Weight, kg	262	143	45
Volume, 10^3 cm^3	45.3	24.6	45
Reliability (failures/10^6 h)	498	116	77
Maintainability Man-hours per flight-hour	0.014	0.0028	80

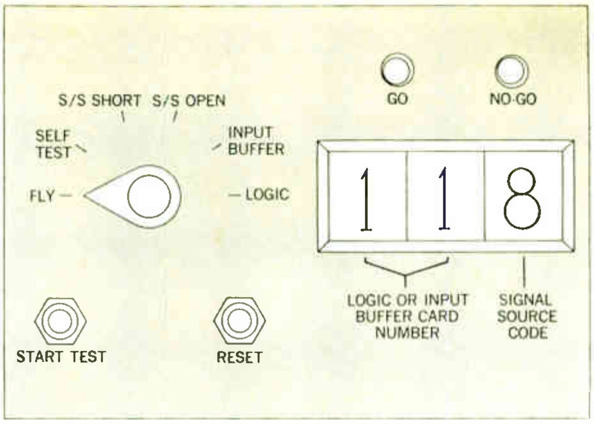


FIGURE 4. BITE control panel.

provide optimum loading of the power source. And by assigning load priorities, it becomes possible to operate an emergency source at optimum capacity. Although the emergency source must first supply power to all emergency loads, automatic bus monitoring permits the plane's pilot to operate lesser priority loads during periods when emergency loads are not "on call." The system also is amenable—unlike electromechanical systems—to ready checkout and a technique was developed to perform preflight go/no-go tests on the low-level-voltage portions of the system. (See box.)

Advanced control logic

As previously noted, Fig. 3 represents a basic system of its sort. A more sophisticated control system—one that is now under investigation—uses multiplexing techniques and consists of the components shown in Fig. 5. The control-signal-sensing and the power-switching approach used in Fig. 3 remain essentially unchanged. Change occurs in the method of handling and processing the control data. Under this more advanced system concept, remote, multiplexed input terminals are located in proximity to large groups of signal sources and thus provide a significant reduction in the length of the wires that gather control information. These terminals monitor each signal source and, upon command from the master control unit (MCU), code and serially transmit the status of each signal source through the multiplexed data-transmission line.

The MCU decodes the received data, solves the Boolean switching equations according to instructions permanently stored within a nondestructible, read-only memory, and then properly transmits coded output data over a multiplexed data transmission line to the addressed remote output terminal. At each remote output terminal, the data are decoded and routed to the particular channel addressed by the MCU. The output of this channel is then "hard-wired" to a specific bus, load, or indicator power controller. The output signal remains constant—either high or low—until the next updating by the MCU.

The MCU obviously is the heart of the data-handling system and controls the entire data-handling process. Changes in its control logic can be accomplished by reprogramming the MCU with instructions from paper or magnetic tape, thereby eliminating the need to make wiring changes in the aircraft. (For reliability, two interchangeable MCUs can be used per system—one operational, the other standby. Parity check and monitor circuits within the MCU provide a continuous built-in test.)

Go/no-go test

This go/no-go test is intended to check out the low-level portions of the solid-state system. Bus controllers and power controllers are not checked and are actually inhibited while the test is in operation. (They, however, are checked as part of the subsystem functional checks.)

The test is divided into four parts: logic, input buffer, signal-source short, and signal-source open as indicated by four positions of the rotary selector switch on the built-in test-equipment (BITE) control panel shown in Fig. 4. When the control switch is in the FLY position, the BITE circuits are disabled and the bus-power and load-power controllers are enabled. Before each test is performed, the reset button is depressed. At the start of each test, both the GO and NO-GO lights illuminate; one of them will be off at the conclusion of each test. A digital indicator identifies the faulty signal source during the "short" and "open" tests. It also pinpoints the faulty input-buffer card during the input-buffer tests.

The logic test checks the logic circuits through all possible input combinations to determine whether they will perform when required. The input-buffer test checks the input buffers to determine whether a signal will pass through them. The signal-source-short test checks for short circuits between the signal leads and the power and ground leads, both in the signal sources and the logic unit. The signal-source-open test checks the signal source's output circuits. The built-in test circuits should be packaged as a part of the logic.

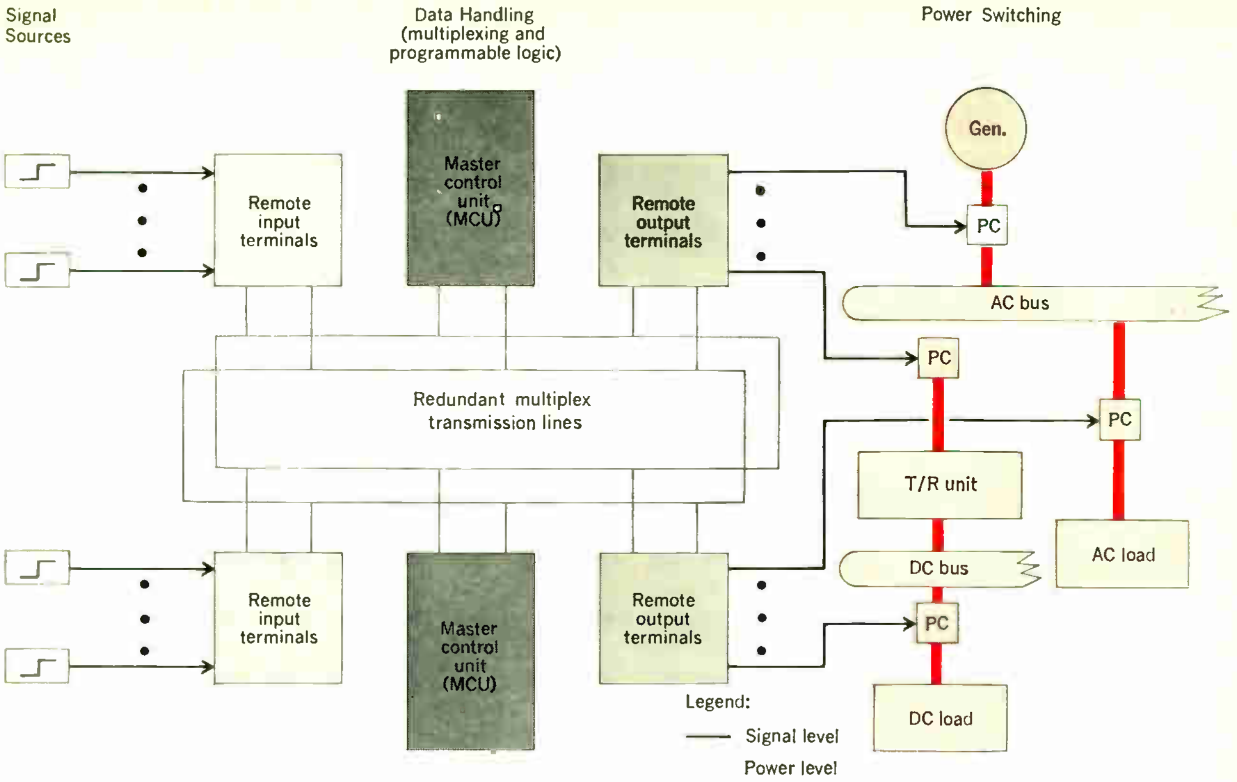


FIGURE 5. A proposed advanced solid-state electric system.

The remote terminals—in their ability to connect with all circuits—are totally redundant. For our particular design, the remote terminals have been optimized at 64 channels each. The package configuration and the circuitry of the remote input terminals are identical; thus these units are interchangeable. The same standardization and interchangeability exist for the output terminals.

The multiplexed data transmission line, indicated in Fig. 5, consists of two pairs of twisted, shielded wires, each forming a closed loop. The transmission lines are redundant and are best routed separately from each other to improve system survivability. Each transmission line can operate either shorted or open. Under this concept, one transmission line can be totally disabled, and the remaining line either open or shorted, and the system will still operate.

The signal sources and control logic can be implemented with minimal development effort using the solid-state circuitry generally in use today. Requirements for the power controllers, however, are many times more severe and make the job of applying semiconductor technology to electric circuit control a difficult one. Therefore, the remainder of this article dwells on the requirements and characteristics of power controllers.

FIGURE 6. Transient-surge, dc-voltage step-function locus limits for category A (per MIL-STD-704A) equipment. The abbreviations ESSL, NSSL, and ASSL in the illustration denote, respectively, emergency steady-state limits, normal steady-state limits, and abnormal steady-state limits.

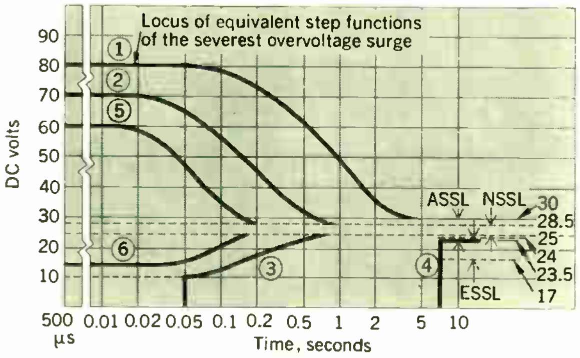
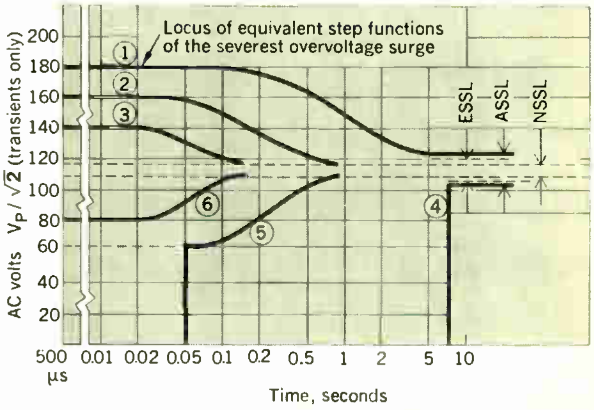


FIGURE 7. Transient-surge, ac-voltage step-function locuses for same category equipment pertinent to Fig. 6. Abbreviations have same meanings as in Fig. 6.



Power controllers

Power controllers must switch electric power in a system satisfying MIL-STD-704 requirements and react to a 5-volt, 10-mA dc signal from the control-logic unit.

Bus-switching controllers are used only to connect power sources to the bus. Load-switching power controllers are used between the bus and the loads to provide control, and current-limiting and circuit protection.

The power controllers have the following operating features:

- Good isolating characteristics between control and power circuits.
- Operating efficiency: 95 percent.
- Voltage drop: 0.5 V dc maximum, 1.5 V ac maximum.
- Leakage current: device rating × 10^{-4} ampere at maximum temperature.
- Operating temperature range: −54 to +85°C.
- No requirement for an external power supply.

Maintaining power controller operation while aircraft bus-voltage level varies is a major problem. Notice in Fig. 6 that the voltage level swings between 10 V dc and 80 V dc, and that in Fig. 7 the ac voltage varies between 60 V rms and 180 V rms. The ac units must also control loads with power factors between zero lagging and 0.4 leading, as shown in Fig. 8.

DC-load power controller

The dc power controller contains a power switch, a regulator, a driver, and circuitry for limiting current and protecting itself (Fig. 9).

Power switch. The power-switching transistor (for our device, an n-p-n silicon power transistor) must have sufficient voltage rating to withstand MIL-STD-704 voltage-transient stipulations and sufficient power dissipation to be compatible with current-limit and circuit-protection modes of operation.

Regulator. The internal regulator is used to provide a buffer effect so that the voltage to the internal circuitry is independent of bus-voltage variations. A Zener diode may be used for low-current power controllers, but a shunt regulator—consisting of a Zener diode, transistor, and resistor—must be used to provide better packaging efficiency for the higher-current units.

Drive circuit. The power transistor must be driven deep into saturation if the voltage drop and power dissipation are to be held to a minimum. This requires a large base current, which typically is one tenth the load-current value. Also, the base-to-emitter and base-to-collector junctions must be forward-biased for saturation. A dc-to-dc converter can be used to provide signal-to-load isolation and the necessary voltage for saturating the transistor. This concept will permit switching power to the load at efficiencies in excess of 95 percent.

Current-limit and circuit protection. There are two reasons for incorporating these features: (1) to protect the unit itself and (2) to protect the circuit it is controlling. The power dissipated in the switching transistor is held to a minimum during normal operation by providing the proper base drive current to cause the transistor to saturate and thus incur a small voltage drop.

During an overload, short circuit, or voltage transient, there is a tendency for the load current to increase, causing the transistor to fall out of saturation and increase its power dissipation. Since the input voltage cannot be controlled by this device, current limiting must be provided to

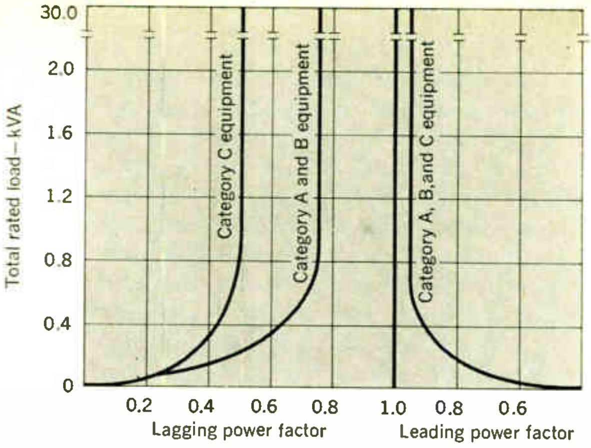


FIGURE 8. Power-factor limits for utilized equipment.

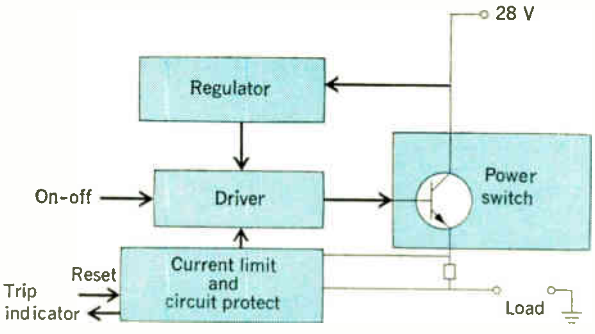


FIGURE 9. DC-load-switching power controller.

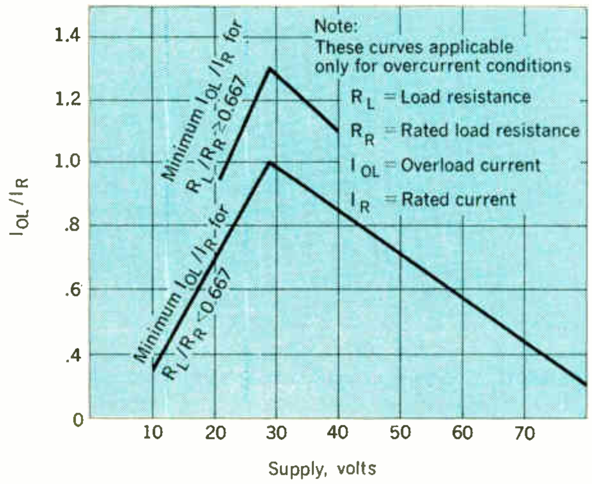
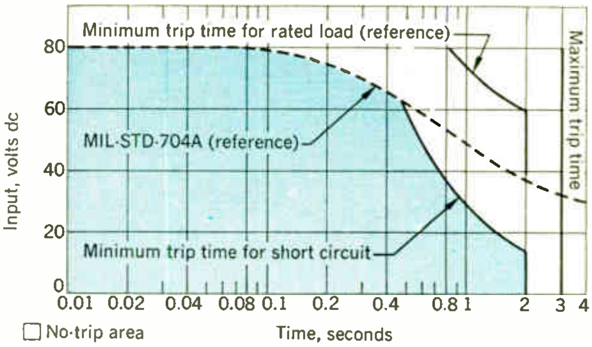


FIGURE 10. Overall current-limiting characteristics of dc power controllers.

FIGURE 11. Trip characteristics for short circuit and/or overvoltage for dc power controllers.



hold power dissipation within limits and prevent the semiconductor junction from rising above rated value during conditions of maximum voltage on the input with the output terminal shorted to ground. Figure 10 shows the current-limiting characteristic specified for the dc power controllers. Notice that at rated voltage (29 V dc), the current is permitted to be limited to: 100 percent rated for a short-circuited device ($R_{\text{load}}/R_{\text{rated}} \leq 0.667$) output and 130 percent rated for an overload ($R_{\text{load}}/R_{\text{rated}} \geq 0.667$).* These limit characteristics, called "foldback," are incorporated to provide current values greater than rated for starting surges, yet allow current reduction to protect the switching transistor during circuit-protection action (current limit and tripout). It would be impractical to design the power controller to dissipate such a large amount of power on a continuous basis, and so a tripout circuit is provided to turn off the power switch and indicate with a trip signal that the action has occurred. Remote reset is accomplished by application of a 5-volt, 10-mA signal (reset) from an external source. Notice that at 29 V dc the tripout time may be between 1 and 3 seconds. (The tripout time must be long enough to prevent nuisance tripping caused by short-lived transients when using a MIL-STD-704 power source [see Fig. 11].)

The ±600-V-dc-spike voltage specifications listed in MIL-STD-704 (Fig. 12) require that special attention be given to both input and output terminals of the device.

AC-load power controller

The ac power controller contains a power switch, a power supply, a driver, circuitry for zero-crossover turn-on, current sensing, and circuit protection (Fig. 13).

Power switch. The power switching elements are back-to-back silicon controlled rectifiers (SCRs). SCRs are ideally suited for this application since they automatically commutate with alternating line voltage.

SCRs also have low leakage currents (1.0 mA or less) in the "off" condition, which enhance their usefulness for power-switching circuits.

The voltage drop of SCRs is higher than that of saturated power transistors, but this is not serious considering that the supply is at 115 volts. The primary requirements of an SCR are that it has sufficient voltage rating to meet MIL-STD-704 voltage characteristics and an I^2t rating

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* The resistance ratio is used to define an overload for a normal operating-voltage range. The device should not limit current or tripout for ratio values between 1.0 and 0.78.

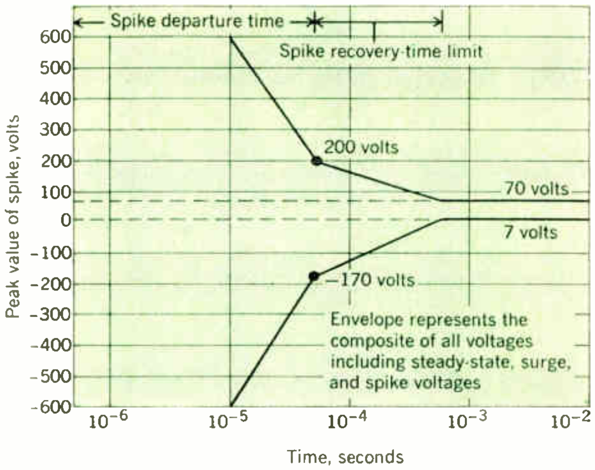


FIGURE 12. Envelope of spike voltages for dc equipment.

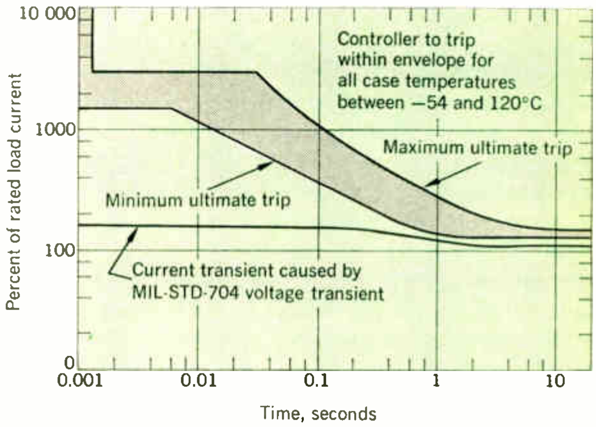


FIGURE 14. Trip characteristics for ac power controllers.

FIGURE 13. AC-load-switching power controller.

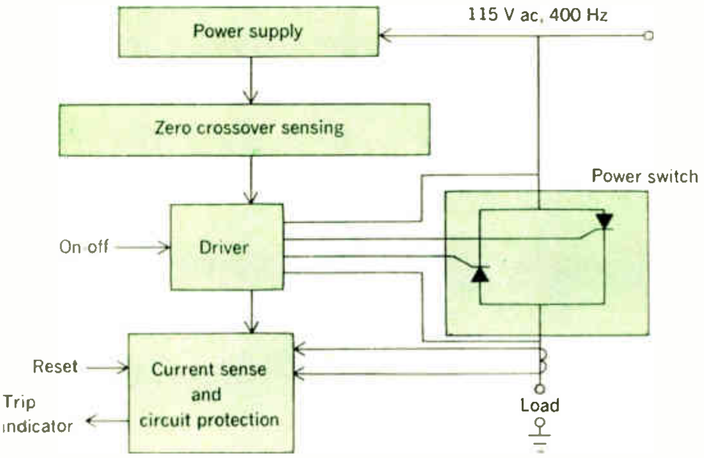
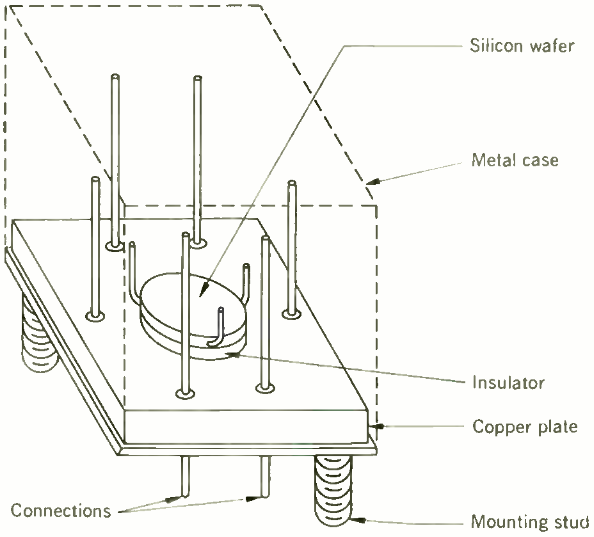


FIGURE 15. Load-switching power controller.



to withstand the high fault current that can occur in the generating system. In a typical 20-kVA system, fault currents of 350 ampere-seconds/phase have been recorded.

SCRs rated for 35 A rms have an I^2t rating of approximately 85. Therefore, very large semiconductor chips must be used or external protection provided by a device (such as a crowbar) on each phase of the bus. Our present plan calls for a crowbar circuit that senses bus current, turns on when the current approaches 140 amperes (peak), and diverts the excess current to ground, allowing use of a 35 A rms SCR chip in the load power controllers.

Application of ac power controllers is limited by half-cycle current rating—particularly in systems using conventional generators—because of their high transient-current capacity. Use of these devices with variable-speed, constant-frequency (VSCF) systems is not limited because transient-current amplitude is controllable.

Power supply. A power supply is required to provide regulated dc excitation for the driver, current-limit, and protection circuitry. The power supply consists of a transformer, full-wave rectifier, filter, and series regulator. This power supply prevents line transients from affecting the internal circuitry.

Drive circuit. To provide isolation between the control circuit and load circuit as well as for power-transfer efficiency, a dc-to-dc converter is used. This concept also provides a continuous gate signal to the SCRs and ensures triggering for any load power factor during steady-state operation.

Zero-crossover sensing. Zero-crossover sensing is required for zero-crossover turn-on. The output from this circuit commands the driver circuit to turn on at zero crossover for starting loads within the device rating.

Circuit protection. As in the dc-load controller, circuit protection must be incorporated into the unit to protect itself as well as the external circuit. SCRs inherently do not limit current as do power transistors. Therefore, it is essential that circuitry be provided to sense time and currents, and to trip out to protect the SCRs. As for the dc-load controllers, the time duration should be long enough to prevent nuisance tripping as a result of line transients (see Fig. 14), or switching loads (such as lamps and motors that allow an inrush of current into the circuit). This can be accomplished by sensing load current and actuating a control circuit that determines the time before tripout. Once tripped out, the device can be reset by applying a reset signal.

Bus-switching power controller

The bus-switching controller performs a relay function only. Transformer rectifier units are used to provide dc power in many systems; therefore, it is important only to discuss ac units.

The ac-bus-switching power-controller block diagram is identical to that shown in Fig. 13 except that it does not contain the current-limiting and protection circuitry. But it does include a lockout feature that is not included in the ac-load controller. High-current SCRs are used. Therefore, I^2t ratings are not a problem. Circuit protection need not be incorporated since circuit protection is provided by the load controllers, which are connected between the bus and the loads. The system concept utilizes a single bus, which makes it imperative not to connect two asynchronous sources simultaneously to the bus. This feature can be designed into the logic, but a latching circuit within the bus power controller provides added protection. The design concept for low distortion and zero-voltage-crossover turn-on is basically the same as for the ac-load power controller.

Package design

Although packaging efficiency is an important factor in determining the size of the power-control module, the power dissipated within the module is of paramount importance. To prevent the junction temperature of devices within the module from exceeding maximum ratings, the heat generated within the module must be conducted away. The low-current devices present no problem, but high-current devices must be attached to an external heat dissipator. Since the junction of the main switching device (power transistor and SCR) is most critical, the thermal resistance between this device and the module surface must be low. To obtain a small package size, integrated circuits, transistors, SCR wafers, and thin-film techniques must be used (as shown in Fig. 15). The objective is to minimize weight by allowing the system designer to treat the power controllers as he would a power transistor and to provide heat sink for the particular application.

The advantages cited for solid-state controllers are emphasized by the results of a study made for the A-7 aircraft in which conventional and solid-state system approaches were compared (Table I).

This article is based on work, initiated in January 1960, directed toward the development of an advanced electric system for aircraft. The effort has been sponsored during the intervening decade by the Navy, Air Force, NASA, and industry.

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New product applications

Digital-to-synchro converters accept parallel binary code inputs and output synchro drive voltage

Each digital-to-synchro (D/S) channel in the series DS1100/2100 converters described here incorporates logic gates and storage for the digital input code. Output circuits are available for driving various types of synchros and resolvers at either 60 or 400 Hz. The block diagram in Fig. 1 shows a representative use where the two different types of inputs are converted to display, control, drive, and compute shaft motions.

The manner in which various input and output options can be used is shown in Fig. 2. Option A (input) is designed for a synchro excitation voltage of 26 or 115 volts rms at 60 or 400 Hz. Input impedance is at least 10 000 ohms. Option B accommodates synchro stator signals, 60 or 400 Hz, 11.8 or 90 volts rms, and option C is for dc coupled signals (sweep waveforms or bipolar dc voltages) 0 to ±5 volts peak, input impedance approximately 10 kΩ.

The converter is provided with options to accept either an angle input code or two successive sine and cosine codes. Up to 12 bits of a single-speed angle code can be handled (multispeed systems are available on special order) or up to 12 bits each for sine and cosine. The format is parallel, straight binary, although either code or the complement of the code is acceptable. The levels to be held are nominal 0 and +5 volts, (DTL) logic (two-unit loads). The update rate has a limit of 25 000 a second.

The channel strobe is a discrete type with single line per channel. Levels are a nominal 0- and +5-volt (DTL) logic (three-unit loads). Duration of the channel strobe is approximately 1 μs, normally in the true state.

The output options are numbered 1 through 5. The first is 11.8- or 22.5-volt rms synchro stator voltages, transformer isolated, peak current limited to 400 mA and 50 mA respectively; the second option provides for 11.8-, 22.5-, or 51.3-volt rms resolver output voltages (for ct operation the sine output only is used) transformer isolated, minimum load resistance 50 kΩ. Option 3, 11.8-volt rms synchro signals, two lines (S1 and S2) direct coupled from power amplifiers and the third line (S3) connected to power-supply common ground. It uses a buffer amplifier to provide specific voltage swing and to drive torque-type loads.

Option 4 (not shown in Fig. 2) represents 3.5-volt rms sine/cos signals direct coupled from operational amplifiers and will drive a minimum load resistance of 1000 ohms. The fifth option provides 11.8- or 90-volt rms synchro stator voltages, transformer isolated, and will drive resonated size 31 or 37 torque receivers. It uses an additional power amplifier stage that may require forced cooling.

All power amplifier outputs incorporate dynamic current limiting and are short-circuit and open-circuit protected. The converter and output circuits contribute negligible distortion so that output waveforms are essentially the same as the reference or analog input waveforms. As to accuracy, the output angle as specified by the synchro voltages will represent the binary input angle to within ±0.1 degree.

Copies of informational brochures and additional details are available from The Bendix Corp., Environmental Science Div., Dept. 81, 1400 Taylor Ave., Baltimore, Md. 21204.

Circle No. 85 on Reader Service Card

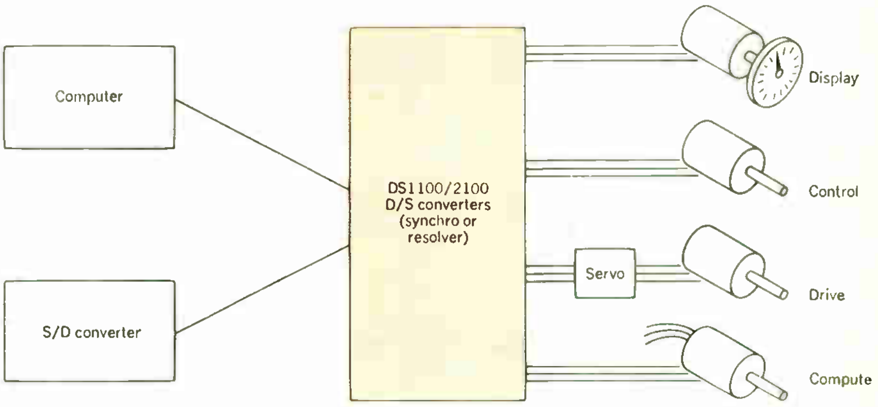

FIGURE 1. Representative system application of the D/S converter.

FIGURE 2. Diagram shows three input and three of five output options.