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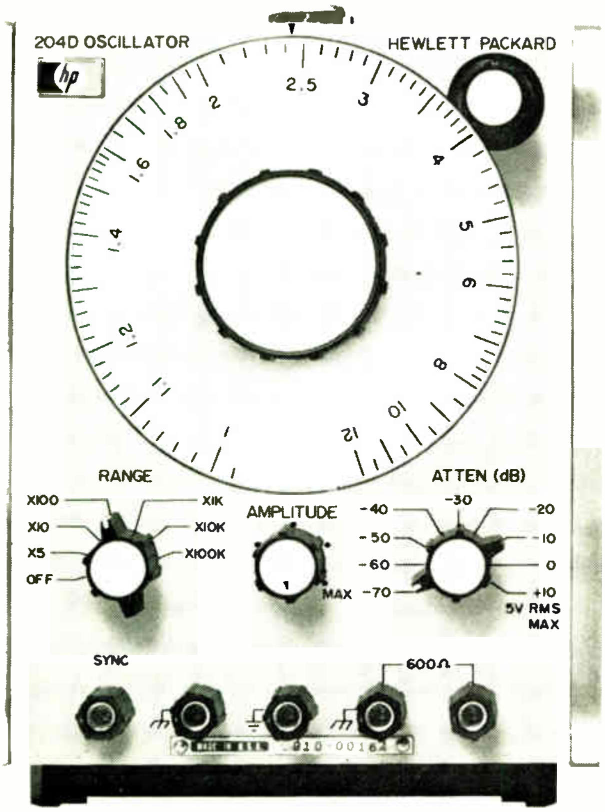

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World Radio History

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.

The exponential crisis

I would like to thank *Spectrum* and Neal Eddy for his article ("The Exponential Crisis," *Spectrum,* August 1970). It was truly encouraging to read a rational, cogent appraisal of the phase lag between technological change and society's adaptability factor.

The sociotechnological equation is already complex and, if valid solutions are to be found, the phase lag obviously must be minimized. Otherwise, technological change cannot be equated automatically with progress.

Improvement of the human lot depends on man's ability to adapt his environment to his needs. Even for those who firmly believe in "back to grass roots" a perception of the raison d'être of technology should not be too difficult. However, harmony between our changing needs and technological change can be preserved only through the symbiotic relationship that Mr. Eddy mentions. The IEEE has the potential for encouraging such a relationship. A "think tank" of such magnitude cannot become an ossified institution. I don't believe the IEEE will.

S. F. Hasnain
Montreal, Que., Canada

The article on "The Exponential Crisis" by Neal Eddy impresses me very much. Mr. Eddy has said a great deal that needs to be said, and has said it well. I agree with his views, in general.

There is one area where I have some doubts—not necessarily disagreements—relating to possible courses of action. Perhaps, in the interest of stimulating additional discussion, I should set these forth.

To illustrate my view, let me resort to some oversimplifications. First, let us say that all decisions are concerned either with a choice between ends to be sought or a choice between means to reach an already selected end. An example of the former is a choice between season tickets to the opera and a vacation in Europe. An example of the choice between means might be the selection between letterpress and offset for printing a publication.

A second oversimplification is that questions of means should be decided by experts, but that selection of the ends to be sought should be decided by the people generally, with as much information about the consequences of the possible choices as the experts—engineers, if you like—can impart to the people.

For the experts to presume to select the ends seems to me wrong. However, as Mr. Eddy suggests in his final paragraph, "preparation of position papers for . . . calling public attention to . . . problem areas" may be a field where we should recognize and accept an important obligation to our fellowmen.

A. V. Loughren
Great Neck, N.Y.

Unemployment solution?

Following is a letter, written by a Spectrum *reader, to President Nixon, presenting the rudiments of a plan to alleviate the unemployment problem currently facing the nation.*

Mr. President:

The waste of our natural resources is a matter of prime concern to the nation. This is a healthy sign, since awareness of a problem is required before a solution can be found.

There is one resource presently being dissipated, however, about which few seem to be aware; hence very little effort is being exerted to conserve it. This resource is the engineer, especially the engineer formerly employed by the large aerospace companies, who is presently unemployed or has been forced to engage in such diverse activities as selling insurance, operating a gasoline station or a tavern, etc.

This is the man who created and developed the complex equipment to enable man to walk on the moon. This is the man whose knowledge and background experience, coupled with curiosity and creative imagination, enabled him to devise the materials, components, and systems to investigate outer space a decade and a half ago. The by-products of his efforts now are being utilized and enjoyed throughout the world (computers, transistorized radios, tape recorders, greaseless frying methods, countless electronic conveniences for the home, jet air travel, etc.)

A tremendous number of these men now can be described as unemployable. They have worked for one company for 10, 15, 20 years or more. They haven't the slightest notion of how to look for a job. Secure in their positions over the years, making fairly decent salaries, they constitute the middle class and upper-middle class of the United States. Now, with responsibilities heavy on their shoulders—children in school and college, heavily mortgaged homes, car payments, etc.—they suddenly find their services no longer required. They feel the sudden panic of insecurity, two thirds of the way through life, in the prime of their working careers, too young for Social Security and too specialized in their fields of knowledge to begin at the bottom again.

These people are truly an unemployable minority!

The writer, in the process of experiencing the frustration described above, has a plan that could conserve this very valuable resource, provide countless benefits to the entire nation, and, at the same time, would encourage students to return to the science and engineering classes from which they fled when the mass layoffs began.

Many of us have the ability and desire to become entrepreneurs—not that we might personally become instantly wealthy—but rather that we might use our knowledge and creativity to better the lot of mankind. We have ideas for new products, new methods, etc., that could create new enterprises, industries, and new job opportunities—products created for man's improvement rather than his destruction. These products would not be "spec'd" to the point that documentation and paper work would cost more than the related product. We all have had our fill of the paper production most of our jobs had degenerated to before the axe fell.

Let funds be made available so that those of us who so desire can convert these products to reality. We have the technical ability to develop products to help medicine, law enforcement, agriculture, transportation. We lack the money for facilities and equipment. Our skills and interests have been directed to technical creativity and innovation, and we lack general know-how in marketing, business management, and so on. This plan could be implemented in the same manner as the G.I. Bill for ex-servicemen. It is no secret that the G.I. Bill was one of the most profitable ventures in which the government has ever engaged. For a few thousand dollars invested in the education of a veteran, federal, state, and local governments have received many times the investment back in taxes plus outstanding achievements such as moon landings, miniature computers, Polaris missiles for defense, supersonic jets, plastics, advancements in television.

Machinery to put this plan into action


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already exists within the federal government. The SBA could review presentations or applications prepared by the engineers. Experts such as SCORE members could advise engineering applicants on the preparation of their plans and proposals. Creative and managerial talents could be brought together by means of computers, using data available from previous employers, state unemployment offices, and the applicants themselves.

Some enterprises will fail but the majority can succeed. The resulting benefits to the nation could be astronomical. The danger of technical obsolescence within the next ten years, which this nation now faces, will be greatly alleviated as students begin to see that a future in science and engineering is not a "short term deal" and return to these classes.

Meanwhile, we who presently find ourselves members of the most ignored, unemployed minority group in the nation would be given an opportunity to resume our efforts as useful, productive citizens and regain our self-respect.

Very respectfully yours,
Milt M. Silverstein
San Jose, Calif.

The future of transportation

In discussing the future of ground transportation ("Planning the Coordination of Ground Transport," *IEEE Spectrum*, October 1970), Dr. Gibson has undoubtedly raised the pertinent questions: What is the city for? Who needs to travel (and why)?

The function of the city is to facilitate communication. It was ever thus. Civilization is a product of communication (instruction, trade, argument) and it happens only in cities. Recently, the limited interaction available through narrow-band technology has stretched the city's limits, but it hasn't made travel obsolete.

So, the city must adapt to the changing technology of communication. It is both necessary and impossible to plan correctly. We can't afford to rebuild our cities very often—how can we foresee the direction of change? Are there any basic principles to fall back on? One would seem to be that communication is the essence; other functions may come and go.

"Life style" does indeed intrude on these musings. The transportation problem will find a suboptimum solution unless it is related to even larger questions. How do we want to live? Where? And again, Why? Downtown used to be the best address of all. If the enhancement of living is accepted as a goal, mobility will be seen in its proper perspective. Another solution like the personal automobile we don't need.

For a start, I like Dr. Gibson's "square" city—80 km by four blocks, with equal travel time in both dimensions. But why only 80 km? Suppose that Skinnyville just keeps going? What if its narrow filaments extend from coast to coast, from border to border? "Downtown" is the communication corridor, where freeway, rail, pipeline, and waveguide attract population and stimulate business activity. This urban network would seem to be a feasible replacement for the nuclear city. Its rationale is communication, including personal travel and commodity movement—now and forever the justification for people crowding together. In the city, mobility, communication, and exchange are developed *à outrance;* elsewhere, you take your chances. The next town is only minutes away, but the vacation spot in the hills may take a few hours. Population is moderately dense in one direction; orthogonally, the countryside is only a few blocks away.

The possibilities are intriguing, but this is not the place to expound a new utopia. One interesting point is that we seem to be heading this way already. The interstate highway system will certainly be a magnet for the rural population; exurbia will arrange itself along the same routes. It remains only to assert federal dominance over the immediately adjacent territory to place the problems where they belong, and make the national city a political possibility.

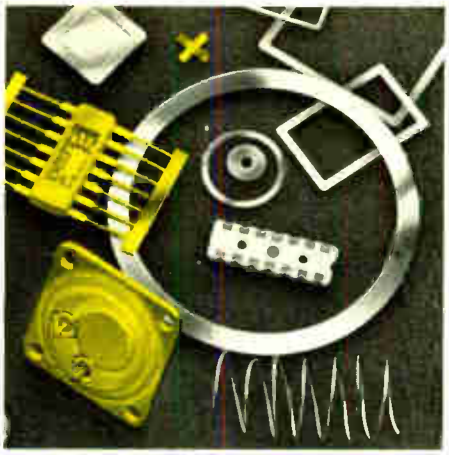
William F. Janeway
Santa Barbara, Calif.

Industry can help

Dr. Van Valkenburg's question "Can Industry Help?" (see "Spectral Lines" in the April 1970 issue of *Spectrum*) can be answered positively. Our experience with Cleveland-based industries has been very rewarding over the past two years. The rewards, however, do not come without a concentrated effort on the part of the dean and department chairmen working closely with industry to make their needs known.

We have used three means of informing industry of our needs to carry out new programs and to expand existing ones. First of all, many of the graduates of the former Fenn College (the nucleus of Cleveland State University, which was founded in 1965, and now the Fenn College of Engineering of Cleveland State University) are employed in the greater Cleveland area. These alumni are informed of our new programs through regular letters from the dean. Since inauguration of the graduate M.S. program three years ago, many of the recent graduates are still in contact with us and, thereby, know our programs well. They, in turn, watch for equipment that they can use and which their employer may wish to donate to C.S.U.

Second, we prepared a booklet that



SCIENCE/SCOPE

The first Intelsat IV communications satellite has been readied for delivery to Comsat by Hughes, prime contractor to the International Telecommunications Satellite Consortium (Intelsat) and is scheduled for launch this winter. The 17½-foot-high satellite will be capable of relaying 3,000 to 9,000 two-way telephone calls, depending on the mode used, or 12 color television programs, or any combination of communications including data and facsimile, from its synchronous orbit 22,300 miles above Earth. Intelsat recently contracted with Hughes for four additional satellites, making a total of eight.

Los Angeles' overburdened communications system is under the scrutiny of aerospace technology. A team of Hughes scientists is at work on a special study aimed at giving the city's emergency services -- police, fire, and ambulance -- a modern command-and-control system. They are evaluating the efficacy of equipping all police vehicles and control centers with electronic devices that would make it possible to determine every vehicle's location almost instantaneously in order to speed the nearest patrol car or cars to respond to a specific situation.

A temperature/humidity infrared radiometer (THIR) for the next two versions of NASA's Nimbus weather satellite is being built by Santa Barbara Research Center, a Hughes subsidiary. The THIR is a two-channel, high-resolution scanning radiometer which measures the earth's terrestrial, cloud, and atmospheric radiation to provide day-night cloud maps and moisture distribution on a global basis. The timely information it will provide on storm buildups and movements is expected to aid in weather forecasting.

A new insulation to shield wiring from high heat has been developed by Hughes research chemists for the U.S. Air Force Materials Laboratory. Electrical wiring coated with the polymeric material can withstand temperatures of 600°F. indefinitely -- or 700°F. for short periods -- without degradation or danger of fire. The new material, in development for nearly two years, also seals wire against the effects of moisture and air and maintains its flexibility down to -100°F.

Needed at Hughes: analog and digital circuit designers experienced in the design of digital-to-synchro and synchro-to-digital converters, feedback amplifiers and active filters, and high-speed digital equipment using LSI/MSI techniques for radar signal processing. Also: logic designers for display applications; microelectronic applications engineers with thick- and thin-film hybrid circuit design experience. EE degree and U.S. citizenship required. Please write: Mr. R. S. Roth, Hughes Aircraft Company, P. O. Box 3310, Fullerton, Calif. 92634. Hughes is an equal opportunity employer.

A supersensitive level sensor invented by a Hughes scientist is so accurate that it could level an imaginary beam 100 miles long to within 1/32-inch of true level. It is now being used by various government and private agencies in tilt measuring instruments, leveling systems, and level reference bases. At Hughes, for example, the sensor holds a 3600-pound granite block level for 15 hours during the final testing of accelerometers for the inertial guidance system of the U.S. Navy's Poseidon missile -- despite vibrations, temperature variations, tides and earth tremors.

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lists the most needed equipment for the next academic year to expand our scope of activities in certain areas. This booklet, with listings by department, which indicates the names of the manufacturers and the pieces of equipment desired along with their costs, is then sent to the local industries. They may have a specific item that they are willing to donate or, in some cases, they make contributions toward a specific item. As one example of the latter, a local electric utility company gave us a grant to purchase new machines for our electric machinery lab, since we are going to retain electric power and machines in our curriculum to supply the industries with the men they need in this area. Other items received through this approach have been analog computer components, recorders, an electromagnet, and a laser system for surveying.

The third method is that of personal contact with the industries. Industries have welcomed us to come and talk with them about their specific requirements for engineering employees and discuss how we may work together cooperatively. They are interested in our present programs and in the future plans for the Fenn College of Engineering since the majority of our graduates are employed in the greater Cleveland area. During discussions with the vice president or manager of engineering, research director, chief engineer, or personnel manager of the company, our needs are made known. The companies often offer to be on the lookout for the equipment they may be able to provide. One local instrument manufacturer and several individuals have donated almost all the equipment necessary to run a laboratory in our new engineering technology program, which began in September 1970. Other gifts coming from these discussions have been specialized electric machines, die-casting machinery, new solid-state components, controllers, an electron probe, and recorders.

Therefore, with a team effort such as we have had making industry aware of our specific programs and needs, we have been offered equipment valued in excess of $500 000 during the past two years. We have not been able to use all of this for various reasons and, in those cases, we have suggested other institutions that might make use of it. We have accepted equipment valued in excess of $200 000 over the past two years.

The answer to the initial question "Can Industry Help?" has been a very positive yes for us and I feel it can be for many institutions near an industrial center who are willing to put forth a concentrated effort.

Ronald G. Schultz
Department of Electrical Engineering
Cleveland State University, Ohio

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World Radio History

VOLUME 7 ☐ NUMBER 12 IEEE spectrum DECEMBER 1970

Spectral lines

Standards are important. In the membership attitude survey carried out in 1968, 39 percent of those polled indicated that issuing standards was a principal way in which IEEE served its members. As a result, the Technical Activities Board appointed a special committee under I. G. Easton to recommend a policy through which the Standards Committee would carry out the total standards responsibility of IEEE.

The Easton committee made several recommendations that have now been implemented:

1. Increase the Standards staff.
2. Publish IEEE Standards in *Transactions*.
3. Review IEEE Standards on a five-year basis.
4. Submit IEEE Standards to the American National Standards Institute.
5. Most important of all, stimulate Group activity in the standards field, so that activities are carried out in all areas of IEEE technical competence.

We are showing progress in all of these areas. A Manager of Standards Operations has been added to the IEEE staff. Recent IEEE Standards have been appearing in *Transactions*. A systematic review of the nearly 150 standards that are more than five years old has been conducted, and our documents are being routinely submitted to ANSI for adoption as American National Standards.

The technical work of generating IEEE Standards should be performed, for the most part, within the Groups. A number of the Groups are carrying on standards activity that is satisfactory both in quality and quantity. However, several of the key Groups of the Institute have little or no standards activity. It is essential that we stimulate the proper degree of activity within those Groups that are not implementing adequate standards programs. It is also important that the many standards activities in which IEEE members participate result in the publication and distribution of IEEE Standards.

A case in point. Many IEEE technical committees have been contributing their time, energy, and expertise in the generation of valuable standards documents as a result of participation in the activities of the American National Standards Institute. The documents thus created represent the best efforts of key members of IEEE, yet the adoption of these documents as IEEE Standards as well as American National Standards is often bypassed. The submission of such documents to the Standards Committee *for adoption as IEEE Standards* still will provide for their routine submission as American National Standards and, in addition, will strengthen IEEE's role in the standardization area. The Technical Committee also will get the added support of the IEEE Standards staff, and the document will be published in the appropriate Group *Transactions*, at Headquarters expense, giving the document broad exposure, both nationally and among our non-U.S. membership.

Some past practices of the IEEE Standards Committee have led to long delays in the publication of Institute Standards. To expedite operations the committee has now gone through a substantial reorganization and has become primarily an administrative body. It examines standards with a view to assuring that they are within the policy framework of IEEE, are valid and needed documents, have been properly coordinated, and represent a consensus of responsible opinion within the Institute. To promote the flow of new documents, it proposes programs of work, gives direction and guidance to standards-writing committees, and assumes responsibility for the administrative work relative to the publication of standards: in *Transactions*, as individual IEEE Standards publications, and as ANSI documents. It monitors the maintenance of standards in an up-to-date condition by initiating, within the appropriate technical committees, actions to reaffirm and revise documents within the specified time periods and to withdraw documents that may be obsolete. It also attempts to incorporate IEC and ISO Recommendations into IEEE Standards and encourages and subsidizes the work of committee members in international standards work.

The Institute has delegated to the IEEE Standards Committee the responsibility for encouraging and coordinating IEEE Standards activity. Being one of the very few committees that *represents* the IEEE, it develops the IEEE technical position in matters concerned with standardization. The committee carries out its work principally through the production of IEEE Standards publications and it needs to produce useful standards efficiently and in quantity so that IEEE can function as a viable standards organization. We need the help of the Groups, of the technical committees, and of our members.

Bruce B. Barrow
Chairman, IEEE Standards Committee

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Stepper motors:
application and selection

Stepper motors accept applied signals and transform them into increments of rotational movement. However, the choice of an appropriate motor will depend upon matching output torque and versatility to system needs

Anthony J. Bianculli Radio Corporation of America

A common denominator of most sophisticated manufacturing equipment is a positioning system. A part or workpiece must be brought into a predefined location envelope so that operations may be performed upon it. Since much of this type of manufacturing equipment is computer-controlled, flexible positioning systems are necessary to derive all of the advantages that the computer can provide. Flexibility can be achieved via closed- or open-loop motor-driven systems—each offering distinct advantages. But whereas stepper motors are optional in the former instance, for an open-loop system, a digital driving device such as a stepper motor must be used to maintain control

It is often desirable when designing electric or electronic equipment to convert digital pulses into positional changes—or vice versa. Many electrically driven mechanical systems such as machining devices and paper feeds are dependent upon such a conversion. The concept also can be used, reversibly, to translate digital signals into analog voltages.

Stepper motors are very practical devices for converting digital-pulse inputs into analog shaft-output (or rotary) motions. Each shaft revolution can be expressed in terms of a number of discrete identical steps, or increments. Each step can be triggered by a single pulse. Many devices that provide incremental rotary motion can serve as stepper motors. These include "true" motors, rotary solenoids, electromagnetic slip clutches, and linear–rotary actuators. True stepper motors are permanent-magnet or variable-reluctance types.

Operating principles

Permanent-magnet stepper motors. In these devices, the rotor is a cylindrical permanent magnet that is magnetized along a diameter, and may have one or more pairs of poles. The rotor rotates in a slotted stator containing windings. In operation, the rotor lines up with the stator magnetic field produced by applying dc voltages to the stator windings. By switching the polarity of the dc voltages, the stator field (and consequently the rotor) is made to rotate.

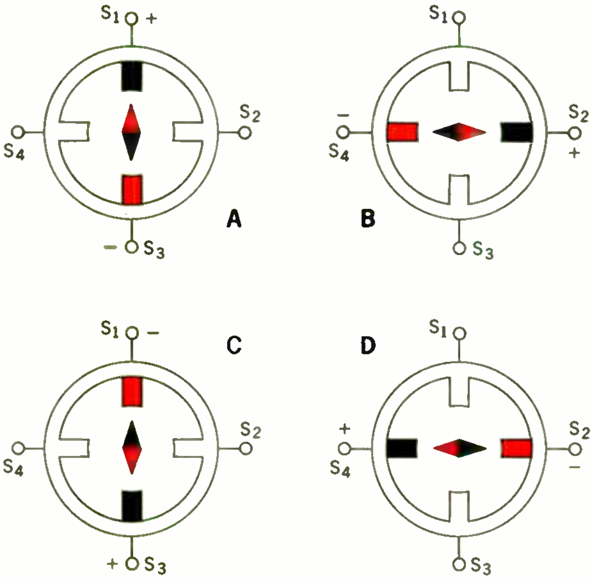


FIGURE 1. Polarity-sequencing permanent-magnet stepper motor. Color indicates a north pole. Diagram segments A, B, C, and D refer to step positions 1, 2, 3, and 4.

I. Switching mode A (90-degree step angle)

Step Position	S_1	S_2	S_3	S_4
1	+	0	−	0
2	0	+	0	−
3	−	0	+	0
4	0	−	0	+

Polarity sequencing to obtain 90-degree stepping is depicted in Fig. 1. When S_1 is positive and S_3 is negative, a magnetic field is produced by the stator causing the rotor to line up with this field as shown in Fig. 1(A). If positive, polarity is switched from S_1 to S_2 and negative polarity is switched from S_3 to S_4, the magnetic field and rotor alignment shift 90 degrees as shown in Fig. 1(B). Subsequent polarity changes [Figs. 1(C) and 1(D)] advance the stator field, and thus the rotor, through 360 degrees in 90-degree steps. See Table I.

It is also possible to obtain 90-degree stepping by using the resultant of two fields. This sequencing mode is shown in Table II. Since in switching mode *B*, both windings are energized at the same time, current and power input are 100 percent higher than in switching mode *A*, but torque is only 41 percent higher. A 45-degree stepping

II. Switching mode B (90-degree step angle)

Step Position	S_1	S_2	S_3	S_4
1	+	+	–	–
2	–	+	+	–
3	–	–	+	+
4	+	–	–	+

III. Switching mode C (45-degree step angle)

Step Position	S_1	S_2	S_3	S_4
1	+	0	–	0
2	+	+	–	–
3	0	+	0	–
4	–	+	+	–
5	–	0	+	0
6	–	–	+	+
7	0	–	0	+
8	+	–	–	+

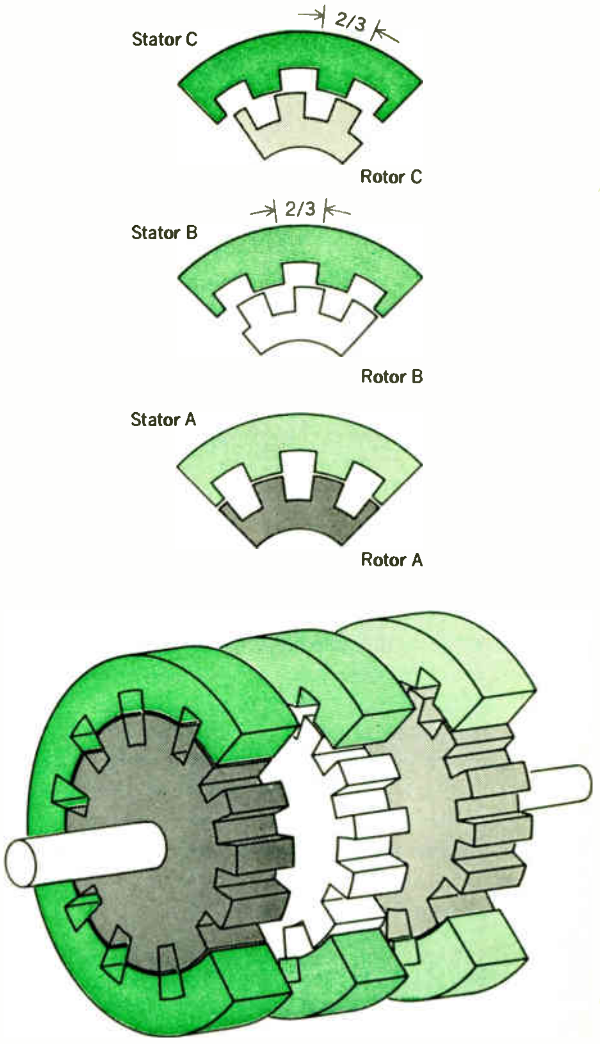


FIGURE 2. Variable-reluctance stepper motor. (Courtesy Warner Electric Brake and Clutch Co.)

mode can also be obtained, as shown in Table III.

The polarity switching delineated in the tables is readily accomplished with mechanical switching devices, but solid-state electronic switching is difficult because two polarities must be switched. To simplify electronic driving circuits, multiphase stepper motors with a center tap in each winding are generally employed.

Variable-reluctance stepper motors. In a variable-reluctance stepper motor, stator–rotor phases are aligned in a shaft. The soft-iron stators are magnetically and electrically independent and the nonmagnetic rotors are all fixed to the shaft. Figure 2 shows an arrangement consisting of three stator–rotor phases: *A*, *B*, and *C*.

Each stator and rotor has the same number of teeth, and all stator teeth in all phases are aligned with each other. Rotor teeth in each phase are slightly offset from teeth in adjacent phases—the amount of offset depending upon the number of phases. In the case illustrated in Fig. 2, the rotor teeth in each phase are offset by two thirds of a tooth width. When one rotor is fully aligned with its stator, the other rotors are misaligned by two thirds the width of a tooth, in opposite directions.

When phase *A* is energized, the teeth of rotor *A* and stator *A* will be aligned. Now, if phase *A* is deenergized and phase *B* is energized simultaneously, the teeth of rotor *B* will adopt a position of minimum reluctance by moving into alignment with the teeth of stator *B*. In the arrangement shown in Fig. 2, the shaft will move one step in a clockwise direction each time the stators are energized or pulsed, in the sequence *A*, *B*, *C*, *A*,· · ·. Pulsing *A*, *C*, *B*, *A*,· · · causes counterclockwise motion.

The index angle, or angular rotation of the shaft per step, in a variable-reluctance stepper motor, is obtained by dividing 360 degrees by the product of the number of teeth and the number of phases.

Other types of stepper 'motors.' Other devices, some of which will be described, are also used for the stepper-motor function. In general, they are not as fast-acting, have shorter life, are unidirectional, and are available in more limited step sizes than true stepper motors.

One stepping device employs an electric coil mounted in a "stator" case having three inclined raceways. An "armature," capable of moving axially, has mating raceways. Steel balls separate the raceways. Activation of the coil pulls the armature toward the coil, and the applied linear force causes the armature plate to rotate because of the slope and arc of the raceways. A clutch engages the output shaft, which turns and detents at the end of the stroke. Deactivation of the coil returns the armature to the start position, ready for the next step.

A different device, which consists of a solenoid coil and a spring-driven plunger, is also available. Upon energization of the solenoid, the plunger is pulled into the coil against the force of the drive spring. Upon deenergization, the spring drives the plunger out of the coil, rotating a multistep star wheel on the output shaft. An actuator prevents the shaft from moving any more than one step, and a stop pawl prevents opposite movement.

One manufacturer makes a "digital motor" with an armature similar to that of a dc motor except that it moves in a direction dependent upon which field coils are energized. When the armature moves, a number of pawls actuate a cylindrical star wheel having teeth on its outside and inside circumferences. The inside teeth drive

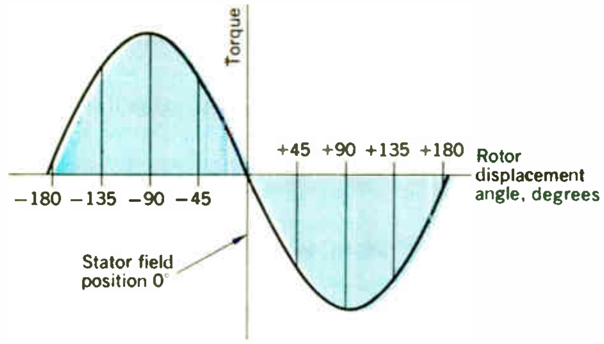


FIGURE 3. Torque vs. motor displacement.

FIGURE 4. Stepper-motor characteristics.

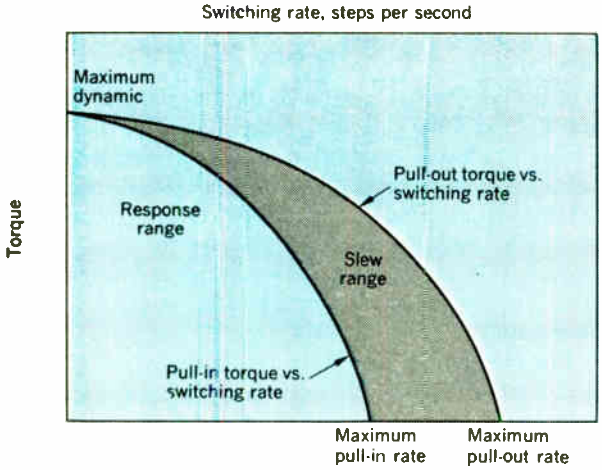
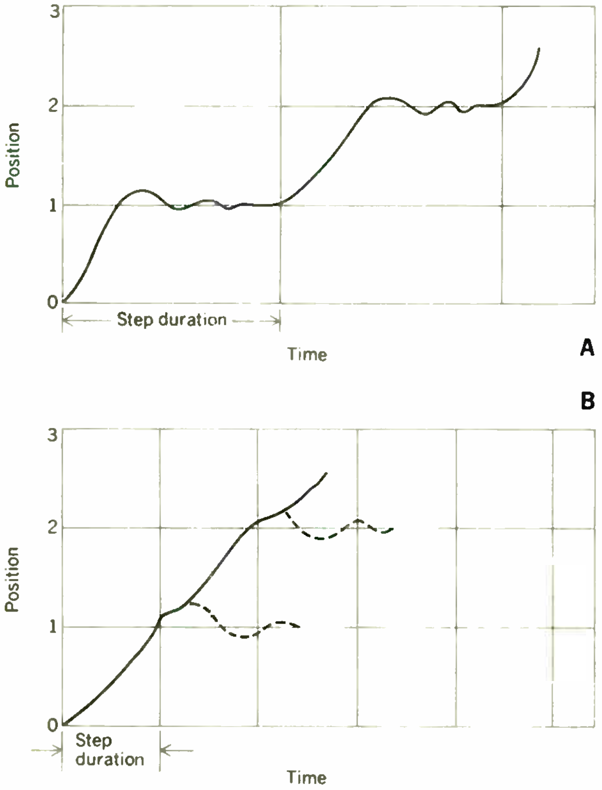


FIGURE 5. Stable operation vs. switching-rate effect. A—Operation below the area of instability in the response region. B—Operation above the area of instability in the response region.



the output shaft via other pawls. When the motor is deenergized, the outer pawls lock the star wheel and motor shaft, and the armature is spring-returned to its initial position.

Electrohydraulic pulse motors combine a true electric stepper motor and a hydraulic torque amplifier. The electric motor drives a four-way pilot valve thus directing oil admission to the hydraulic motor. The design provides a high-speed pulsed output at a very high torque level.

A unique way to achieve very high stepping rates with moderate to high torque outputs is accomplished by USM's Responsyn® stepper motors. These motors employ an adaptation of the Harmonic Drive, a USM-patented power transmission system that combines the functions of electric motor and speed reducer.

Stepper-motor characteristics

As explained earlier, when the rotor of a permanent-magnet stepper lines up with the stator field, so that a rotor *N* pole(s) is aligned with an *S* pole(s) of the stator magnetic field, no motion occurs. Rotation of the stepper-motor rotor is achieved by switching the polarities of the stator field to the next step position, causing the rotor to follow. Obviously, switching of the stator magnetic field must precede rotor rotation and, in the dynamic condition, the rotor is always behind the stator field switching, trying to catch up and align itself, *N* to *S*, with the stator field. This situation is displayed in Fig. 3. When the relative displacement between rotor and stator field is 0 degree—i.e., when *N* and *S* poles align, neither torque nor motion occurs. As soon as an angular difference exists between the two poles, a restoring torque is developed and rotor motion is produced. Maximum torque, called holding torque, is developed when the rotor and stator field positions are 90 degrees apart. The value of holding torque that the stepper-motor manufacturer usually provides should be used only as a figure of merit. The motor cannot drive a load requiring this amount of torque since this is a maximum torque level achieved at only one relative displacement position. A more meaningful indication of the loading capacity of the motor is the pull-out torque, or running torque. From Fig. 4, it is seen that pull-out torque varies with the switching rate. It is limited by inherent damping in the motor, and load inertia has little or no effect.

The lower curve of Fig. 4 describes the pull-in torque. It varies with the total inertia and is a measure of the switching rate at which a motor can start without losing steps. This curve is the upper boundary of the response range, or start range. A motor can start, stop, and reverse on command in the response range; in this range, therefore, a stepper motor can be successfully used as an open-loop positioning device. (A small, nebulous range exists near the curve itself wherein the stepper motor can bring the load into synchronism, but not without losing some steps.)

The area between the two curves is identified as the slew range. The slew range is entered while the motor is running and within it the motor cannot start, stop, or reverse on command. However, the slew range is useful since the motor can run unidirectionally and follow the switching rate within a certain acceleration without step losses while it develops enough torque to overcome the load torque.

Within the response range there is a region where the stepper motor behaves erratically. Stepping occurs but with irregular step angles. Pull-out torque varies considerably and at certain switching rates can actually be lower than at higher rates. This unstable operation is caused by a combined inertia of load and rotor that causes overshoot and, subsequently, an oscillatory motion at the end of a step. Friction, eddy currents, and hysteresis dampen these step-end oscillations (Fig. 5).

Stable operation is achieved through proper selection of the physical and operational parameters of the system, viz., load inertia, damping, and switching rate. For example, if the step duration between pulses is sufficiently long, the next pulse comes after the oscillation has diminished [Fig. 5(A)]. Operation in this mode occurs at a switching rate below the unstable region of erratic operation. Stability can also be achieved at a higher switching rate where the time duration between pulses is equal to, or shorter than, the initial period of the oscillation [Fig. 5(B)]. In both cases, operation is within the response range.

Stepper-motor selection

To select the proper stepper motor for a given system, certain parameters of the system should be known. With this information, it is possible to make a judicious choice from the catalogues of most motor manufacturers.

The first, and most obvious, observation is that the motor must deliver sufficient torque to operate the system. The greatest torque demand on the motor is made when starting the system because, in addition to the torque required to drive the load, inertia effects must be overcome. The total torque requirement may be expressed as

$$T_{\text{total}} = T_{\text{load}} + T_{\text{inertia}} \tag{1}$$

This expression is presented graphically in Fig. 6, which shows the torque demands of the system during the starting and accelerating stage for a constant switching rate, and for stopping. It is well to remember that the starting and stopping stage may involve only one step of the motor. The torque demand for stopping is dependent on the relative values of inertia and load torques. The load torque (friction, eddy currents, and hysteresis effects) aids the slowdown and stop process and, if it is larger than inertia–torque effects, it is entirely possible to stop the motor, in synchronism, without providing a counteracting torque via an electrical input to the motor.

Ordinarily, if it is intended to operate the system "open loop"—i.e., without positional feedback—the motor chosen must provide sufficient torque and stepping speed within the response range. It is only within this range that the motor can start, stop, or reverse on command "instantaneously."

The motor can be driven into the slew range by increasing the switching rate. But once in the slew range, the motor cannot be stopped or reversed instantaneously without losing synchronism. (If a deceleration schedule is preprogrammed into the motor driver, it is possible to maintain synchronism while reducing the slewing rate gradually. In this manner, the motor can be brought back into response-range operation and stopped instantaneously.)

For closed-loop operation, maintenance of synchronism throughout the entire driving cycle is less important since the actual position of the system output is monitored constantly. Efficiency dictates that the system be started and driven as fast as possible, sometimes even with the probability that synchronism will be lost. Unless precautions are taken, the system output will overshoot at the end of travel because of inertial effects. A closed-loop system automatically will correct the overshoot, but at the expense of time. Therefore, it may be desirable to anticipate the end of a run by keeping count of steps actually taken (or distance traveled by the output of the system) in order to provide a controlled deceleration and prevent overshoot.

As mentioned previously, the total maximum torque required of the motor is the summation of load torque and inertia torque. Load torque is defined as the torque required at the system input shaft to move the load. (The small difference between the starting, or breakaway, torque required to overcome stiction, or static friction, and the torque required to maintain dynamic operation—the running torque—is usually negligible.) Although the load torque may be calculated, if the system is available

FIGURE 6. System torque demands.

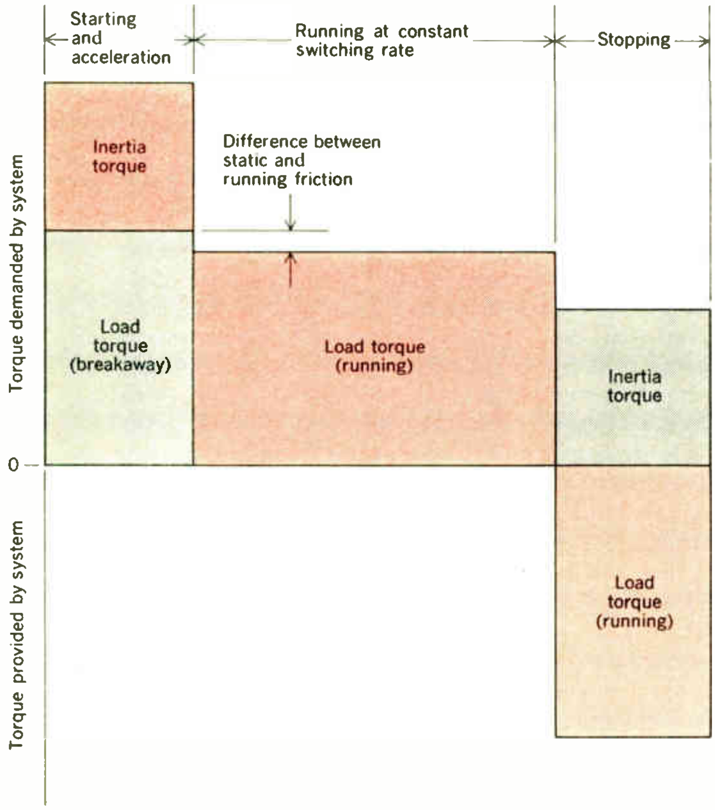
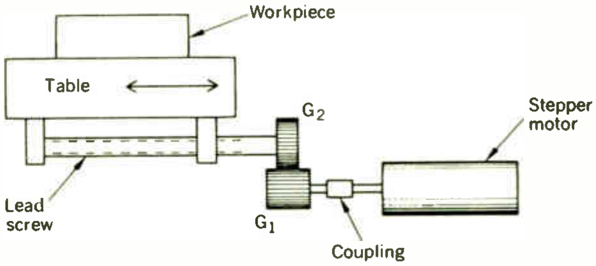


FIGURE 7. A simple positioning system.



before the motor is selected, it is simpler (and probably more accurate) to measure the starting torque by attaching a pulley to the machine shaft that will be coupled directly to the motor. A system of weights or a scale connected to the outside diameter of the pulley can be used to measure the force required at the pulley radius to move the system.

Inertia torque may be determined by calculating the load inertia as applied to the motor shaft. Using the system shown in Fig. 7 as an example, the total inertia of the system (neglecting the coupling inertia) as seen by the motor is

$$I_{\text{total}} = I_{G1} + (I_{G2} + I_{\text{lead screw}}) + I_{\text{table}} \qquad (2)$$

The term in parentheses ($I_{G2} + I_{\text{lead screw}}$) must be calculated as an inertia reflected back to the motor shaft.

The moment of inertia of a solid cylinder or disk of mass (m), radius (r), and of any axial length (L) about its own axis is

$$I_{\text{cylinder}} = \frac{mr^2}{2} = \frac{\pi D^4 L d}{32g} \qquad (3)$$

where D is diameter; d is density; and g is acceleration due to gravity.

Equation (3) is used to find the moment of inertia of gear 1 (and also of the gear 2)–lead-screw combination.

The inertia reflected back to the motor shaft ($I_{G2} + I_{LS}$) equals I_E, and the equivalent torque at the motor shaft (necessary to accelerate gear 2 and the lead screw) equals T_E:

$$T_E = I_E \alpha_1$$

where α is angular acceleration. Also

$$I_E \alpha_1 = I_2 \alpha_2 (N_1/N_2)$$

where N_1 is number of teeth on gear 1 and N_2 is number of teeth on gear 2.

$$T_E = I_2(r_1/r_2)\alpha_1(N_1/N_2) = I_2\alpha_1(N_1/N_2)^2$$

$$I_E = I_2(N_1/N_2)^2 \qquad (4)$$

The last term in Eq. (2), the table (and workpiece) inertia, is determined as follows: The resistance of the table to acceleration equals the force necessary to produce acceleration. This inertia force F is equal to ma. Using the subscript t for the table (and workpiece) and the subscript s for the stepper-motor shaft,

$$F_t = m_t a_t$$

where a is linear acceleration. Torque $T_s = F_t r_1$ where F_t is force reflected to the stepper-motor shaft. F_t is reduced by a factor equal to the mechanical advantage of the system, MA:

$$F_s = F_t / MA$$

where MA = (distance moved by motor shaft)/distance moved by workpiece, δ.

$$T_s = \left(\frac{W}{g}\right) a_t \left(\frac{1}{MA}\right) r_s$$

where W is the combined weight of table and workpiece.

$$T_s = \frac{W}{g}\left(\frac{1}{MA}\right)^2 r_s^2 a_s$$

and

$$I_s = \frac{W}{g}\left(\frac{1}{MA}\right)^2 r_s^2$$

The distance moved by the motor shaft is equal to angular movement in degrees,

$$\beta\left(\frac{\pi}{180}\right) r_s$$

Thus,

$$I_s = \frac{W}{g}\left(\frac{\delta}{\pi\beta/180}\right)^2 \qquad (5)$$

Substituting Eq. (5) in Eq. (2),

$$I_{\text{total}} = I_{G1} + (I_{G2} + I_{LS})\left(\frac{N_1}{N_2}\right)^2 + \frac{W}{g}\left(\frac{\delta}{\pi\beta/180}\right)^2 \qquad (6)$$

and

$$T_{\text{inertia}} = T_{\text{total}}\, \alpha_s$$

The foregoing dissertation concerning stepper-motor torque requirements presumes that most of the physical parameters and design objectives of the system are known. It is worthwhile to look at just one datum to show the dependency of the variables on each other.

Switching rate will fix the angular acceleration term α that must be known for calculating torque needs. The switching rate is, in turn, fixed by the motor step angle and the output speed of the system. The motor step angle affects the resolution, or output positioning of the system. If all other things are equal, the smaller the step angle the more closely the output can be positioned to any predetermined point. It follows that the smaller the step angle the longer the output mechanism will take to move from one point to another. Therefore, a choice of step angle must be a compromise between resolution and speed of the system. The motor step angle, gear ratios, and lead-screw pitch must be known. Then it is possible to work backwards from the desired traverse speed, and ascertain the switching rate. In addition, there are other important factors such as size (maximum and minimum), ambient temperature, holding torque, and detent torque to consider when choosing a stepper motor.

The author thanks L. Rempert for the help he provided by discussing the idiosyncrasies of stepping motors and the discrepancies displayed between theory and practice. Mr. Rempert's experience in the application of these motors was of inestimable value. S. Haas helped to illuminate many fine points about motor torque and inertia analysis, and his assistance is gratefully acknowledged.

Anthony J. Bianculli graduated from the Polytechnic Institute of Brooklyn in 1949 with the B.S. in mechanical engineering. He joined RCA in 1952 as a design engineer in its microwave-tube operations at the Harrison, N.J., plant. There, over the next ten years, he enjoyed a succession of responsibilities. In 1962, prior to his transfer to RCA Laboratories, Princeton, N.J., he was manager of Nuvistor pilot production. Between 1962 and 1968 he was head of device technology at the Laboratories. He is now a member of the Advanced Manufacturing Equipment Research and Development Group—a corporate staff activity. His responsibilities include anticipating and satisfying divisional needs for advanced manufacture.

Integrated-circuit digital logic families

III—ECL and MOS devices

Flexibility, high speed, and excellent speed–power product are among the important features contributing to the growing popularity of emitter-coupled logic devices. Metal oxide semiconductor logic devices are also exhibiting a high growth rate

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

This final installment of a three-part article is devoted to emitter-coupled logic (ECL) devices as well as to metal oxide semiconductor (MOS) logic devices of the p-channel (P-MOS) and complementary (CMOS) types. The concluding portion presents a summary chart comparing the major parameters of the various IC digital families discussed in the three installments, plus a useful check list of available functions.

The next family of logic to be examined is emitter-coupled logic—or, as it is sometimes called, current-mode logic. ECL is different from standard saturating logic in that circuit operation is analogous to that of some linear devices. In this case the transistors do not saturate and logic swings are reduced in amplitude.

Figure 52 shows the most common ECL design, which is that of a four-input OR/NOR gate; the logic symbol is illustrated in Fig. 53. Although the circuitry is quite different, operation is no more complex than TTL. If all four of the inputs shown in Fig. 52 are at a low level (about -1.6 volts), the emitter node (point 3 in the diagram) will be one diode drop below the V_{BB} reference voltage. This potential (about -1.9 volts) keeps the input transistor turned off, and thus no current flows into the collector node, shown as point 1. There is then a negligible voltage drop across the 290-ohm resistor and the base of the NOR output transistor is essentially at ground potential. The NOR output voltage is one diode drop more negative, or a nominal -0.75 volt. It is seen that if one or more of the inputs, A through D, is brought up to a high level (-0.75 volt), current will switch through the 290-ohm resistor, causing a voltage drop. Resistor ratios have been chosen such that the drop across the 290-ohm resistor is about 900 mV. The NOR emitter follower now gives an output of about -1.65 volts. It is observed that the output is *not* high if one or more inputs is high. This defines the NOR positive logic function.

Since the ECL gate input is really a differential amplifier, the voltage drops across the collector resistors will be opposite, or out of phase. For example, when all inputs are low, the reference transistor takes over and supplies current to R_E, causing a drop across the 300-ohm resistor. Since the voltage at point 3 is now slightly lower, with the reference transistor conducting, the current through R_E is decreased. The collector resistor is now made a little larger in value partially to compensate for this. The voltage drop across the 300-ohm resistor is a nominal 850 mV, resulting in an OR output of approximately -1.60 volts. The OR output, as expected, is high if one or more inputs are high. The two collector resistors are kept similar in value to provide output swings that are similar just outside the threshold region, where noise immunity is tested. Internal reference voltage (V_{BB}) determines the switching level of the gate and has been chosen as -1.175 volts, for this design, to give symmetrical noise immunity. R_1, the two diodes, and the 2.3-kΩ resistor yield a V_{BB} level that provides symmetrical noise immunity for both temperature and voltage variations.

The emitter-follower outputs provide a low output impedance of about 15 ohms while translating the voltage drop across the collector resistors back to standard ECL levels. The output characteristics are those of a high-β emitter follower with a 1.5-kΩ pull-down resistor.

It is seen that the OR and NOR logic is performed by the transistors that have their emitters coupled together at node 3 in Fig. 52; hence the name "emitter-coupled logic." The complementary outputs of the gates are very valuable to the logic designer who frequently requires the complement of a variable or term.

The input circuitry of the ECL gate is essentially the same as that used in most operational amplifiers and therefore has similar advantages. Input impedance is of the order of 100 kΩ, which is very high compared with that of other logic circuits. This is observed in the input characteristics for a nominal -0.75-volt input. The high input impedance results in low line currents and therefore decreased di/dt problems in the layout and wiring of a system. Referring to the input characteristics (Fig. 54), note that as the input continues to go more positive, above a maximum "one" level, input current starts to increase. This marks the start of soft saturation and will tend to reduce input ringing. The input, being differential in nature, also provides common-mode rejection of power-supply variations. In fact, the important parameter of noise immunity varies only as $^1/_8$ of the supply variation. Since the linear portion of the transition width (see Fig. 55) is about 120 mV, a large percentage of a logic swing is left over for noise immunity.

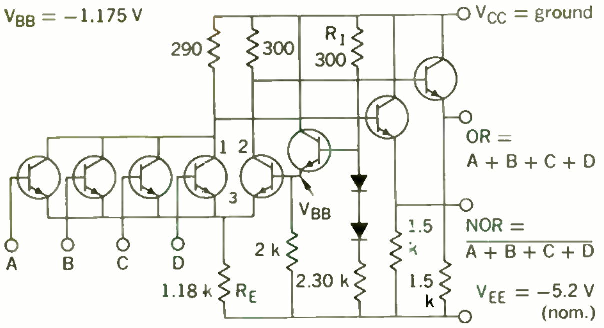


FIGURE 52. Basic ECL gate schematic diagram.

FIGURE 53. Basic ECL gate symbol.

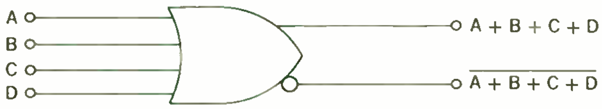
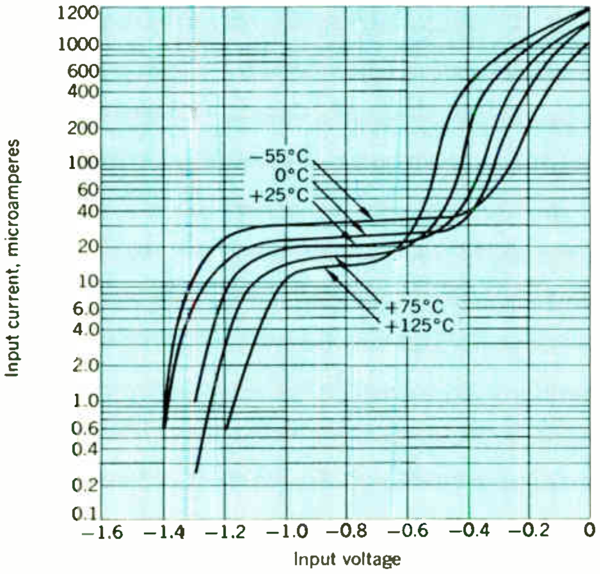


FIGURE 54. Typical ECL input characteristics. Note that the gate does not start drawing current until an input voltage approaching V_{BB} is reached. Note also that as the temperature increases the input transistor will saturate at a lower input voltage. The reason is that the base-collector saturation voltage decreases with temperature, whereas the collector current remains relatively constant.



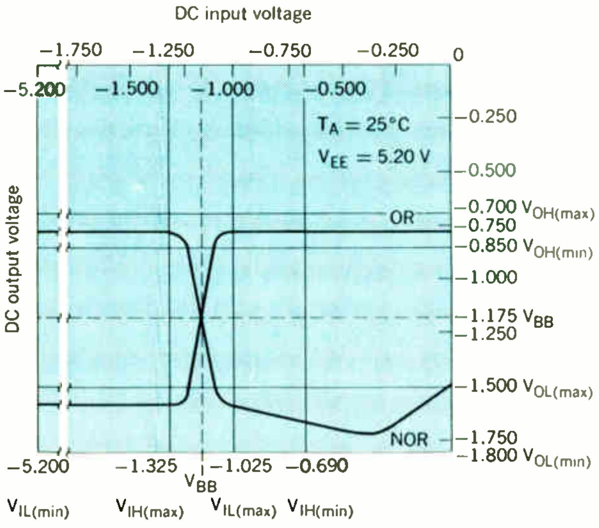


FIGURE 55. Typical ECL transfer characteristics.

I. Voltage specification points

Voltage	Definition
$V_{IH(max)}$	maximum input, high level
$V_{OH(max)}$	maximum output, "1" or high level
$V_{OH(min)}$	minimum output, "1" or high level
$V_{IH(min)}$	minimum input, high-level threshold
$V_{IL(max)}$	maximum input, low-level threshold
$V_{OL(max)}$	maximum output, "0" or low level
$V_{OL(min)}$	minimum output, "0" or low level
$V_{IL(min)}$	minimum input, low level

The various specification points (EIA format) are given in Table I. Noise immunity is determined from the difference between $V_{OH(\text{min})}$ and $V_{IH(\text{min})}$ and $V_{IL(\text{max})}$ and $V_{OL(\text{max})}$. This value is approximately 200 mV, depending upon the design and manufacturer. The design in Fig. 52 provides a compensated V_{BB}, which remains in the center of the logic swing for voltage and temperature variations, giving constant noise immunity regardless of temperature. The OR and NOR transfer characteristics are shown in Figs. 56 and 57. ECL gate design permits operation over a wide power-supply-voltage range since V_{BB} and the low-level output voltages track proportionately.

The noise immunity of the basic circuit is one volt or better looking into the V_{EE} terminal. Since the power-supply voltage is usually subject to greater variations than the system ground, V_{CC} is normally grounded with V_{EE} at −5.2 volts, which represents the optimum tradeoff between speed, noise immunity, and power dissipation. Since the gate outputs are emitter followers, output impedance is low, normally from 5 to 15 ohms. The output load characteristics are shown in Fig. 58.

Comparing the input characteristics in Fig. 54 with the output characteristics, it is obvious that large fanouts are possible if speed is not a consideration. Normally, however, speed is a consideration, and additional capacitance increases ECL fall time. This is a function of current through the pull-down resistor on the gate output and effective load capacitance. The increased fall time is about 0.2 *RC*. Since the ECL gates switch in the center of the logic swing, propagation delay to a negative-going output waveform is increased by 0.1 *RC*. Capacitive loading has a relatively minor effect on rise-time delay because of the very low output impedance of the emitter follower. Fanouts are normally specified at 25, or higher, but for high-speed designs fanout is often limited to 10 or 15 gates.

Processing requirements

Although not as easy to build as RTL, ECL does have some definite processing advantages. The voltage gain of the circuit, which is approximately 6, is essentially independent of transistor β. The output voltage levels depend upon diode drops for a high output or resistor ratios for a low output. Transistor β can vary from a low of about 40 to a high in excess of 300, which permits easy processing limits. Collector–emitter voltages are low, thus easing processing restrictions.

Logic advantages and flexibility of the ECL gate

Complementary outputs add greatly to the flexibility of design and usually eliminate the requirement for extra gates used simply as inverters. The emitter-follower outputs allow various gates to be tied together, thus performing the implied OR positive logic function. Sum-of-products expressions are then easily generated by tying together the gates that generate the individual terms. An example of the implied OR connection is shown in Fig. 59.

Figure 60 illustrates a modification of the implied OR connection where multiple outputs have been added to the basic gate. The fanout capabilities of each of the outputs are independent. This permits heavy loading as in the case of driving 50-ohm loads, as illustrated in Fig. 61. The 50-ohm coax should be terminated in its characteristic impedance. A terminating voltage of about −2 volts is normally utilized. Some gates are designed to drive into 50-ohm impedances directly; recommended termination voltage is the same, which can be obtained from the Thévenin equivalent, as illustrated in Fig. 62.

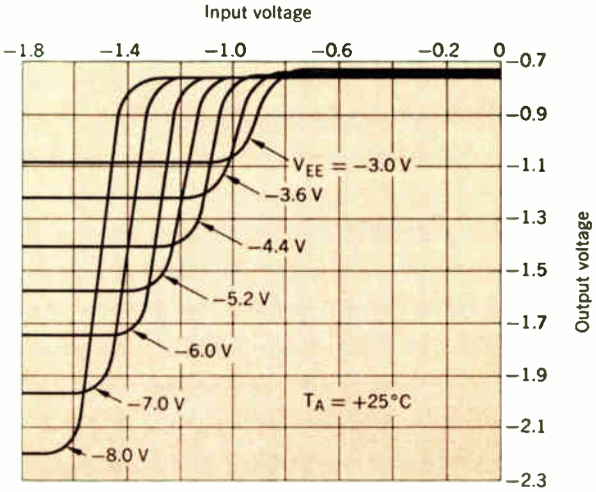
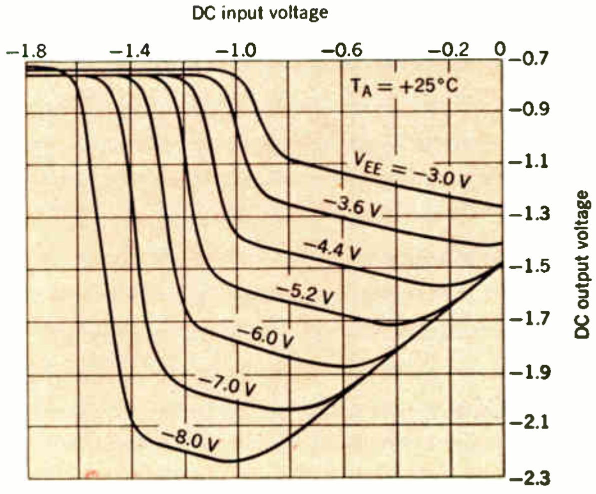


FIGURE 56. Typical OR transfer characteristics for ECL. Note the squareness of the curves. The transition width from knee to knee remains constant at about 200 mV at 25°C. The output voltage remains constant even if the input saturates. Note how the output voltage swing is proportional to the supply voltage V_{EE}.

FIGURE 57. Typical NOR transfer characteristics for ECL. The NOR transition width is the same as for OR. Note the 1-to-4 slope of the output voltage as the input is increased above threshold. Increased input voltage causes increased emitter voltage, which, in turn, increases the current through the collector resistor. The collector resistor value is a quarter of that of the emitter resistor—hence the 1-to-4 slope. Note the saturation region, where the output voltage begins to go more positive because of saturation of the base-collector diode.



Balanced twisted-pair line driving and receiving

One of the largest systems problems is that of driving long lines and distributing clock waveforms. High-bandwidth low-noise generation, along with good noise immunity, is desirable. It is easily obtained by the use of ECL gates and flip-flops, with their complementary outputs and differential inputs; see Fig. 63.

The method is very effective from a noise point of view; external radiated fields are canceled out by the use of twisted wire, and noise from external sources becomes common mode. This technique results in a noise immunity of one volt or more over the temperature range—a result that is superior to that of the various forms of saturated logic, except for HTL. Line lengths of 100 meters have been driven successfully in large systems.

AC advantages

Recent ECL exhibits the industry's best speed–power product for high-speed systems and has the shortest propagation delay of any logic form. The current drain is essentially constant regardless of frequency and without switching transients caused by commutation; thus, power supply bypassing is an easily solved problem. The relatively slow rise and fall times (compared with gate propagation delay) and the low line currents minimize the *di*/*dt* and crosstalk problems that are all too common in computer back planes. The extensive use of "implied OR" saves cost and power dissipation through the elimination of unnecessary gates. Since the complementary outputs switch at the same time, the gate can easily drive a balanced twisted-pair line as was shown in Fig. 63. The twisted-pair line is terminated, preventing reflections, while information is received differentially by a ECL gate that has both sides of the differential amplifier available.

Circuit modifications for increased flexibility

It is also possible to form a transistor tree, building up from a current source as shown in Fig. 64. This permits an even better speed–power product, since the same current source may be used three times over, per logic decision. This technique is often used in ECL complex functions and in direct-coupled flip-flops. The technique permits two or three levels of the positive logic AND or NAND function to be implemented. Thus OR, NOR, AND, and NAND are all available in positive logic.

Observing the sum-generating portion of the full-adder circuit, we see that if inputs A and B and C_i are all at a high level, current is switched through the left portion of the "tree," causing a voltage drop across the 300-ohm resistor attached to the base of the SUM NOT output. That is, SUM NOT is false and the SUM is true or at a high level. Note that the ADD tree generates all eight possible combinations of A, B, and C_i inputs. Compensated bias levels provide the switching points and set operating currents.

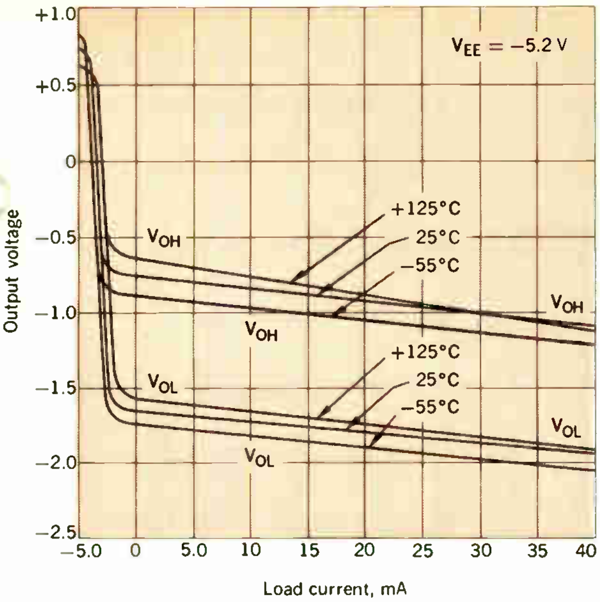
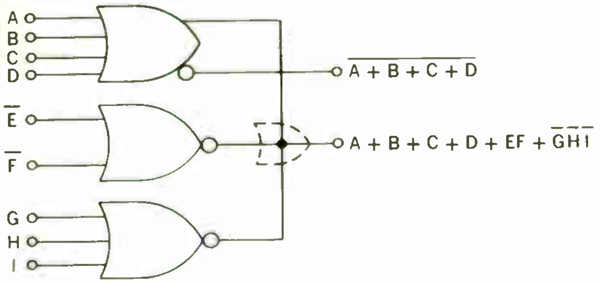


FIGURE 58. Typical ECL output characteristics. These curves illustrate the low output impedance at both the high and low output levels. Output voltage is normally specified at 2.5 mA but remains relatively constant for much larger loads. A low-level output can be forced higher by supplying sufficient current to the emitter resistor from an external source. This may occur during "implied OR" conditions.

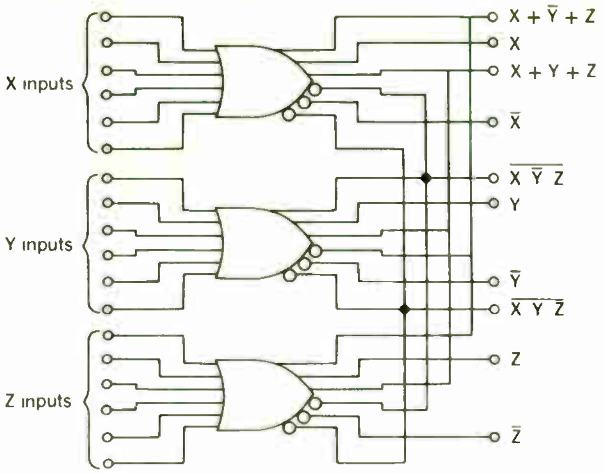
FIGURE 59. "Implied OR" example. One or two pull-down resistors can be used. If more than three outputs are to be tied together, gates with open emitters should be used.



The basic ECL gate can also be modified to provide the OR/AND function with essentially one level of gating (Fig. 65). This type of function often appears in the random logic area of computer design. The circuit exhibits an excellent speed-power product analogous to that of the "implied OR" function. The disadvantage of this circuit is that the number of input clusters is limited by the V-clamp current capabilities. Also, with all inputs at a low level, the V-clamp supplies the extra current required by the additional differential-amplifier current sources. The low-level output voltage then temperature-tracks at a rate of two diode drops, which is greater than normal.

Higher-speed ECL

The basic ECL circuit lends itself to very-high-speed operation because of the small voltage swings and the use of nonsaturating transistors. Speed has been emphasized in the industry, resulting in two basic groupings of ECL logic, with 1-ns or 2-ns delay time. Figure 66 illustrates



where
X = f (six input variables)
Y = f (six input variables)
Z = f (six input variables)

Average propagation delay = 5.0 ns
Total power = 200 mW

FIGURE 60. Independent implied OR. Multiple emitter-follower outputs allow independent operation; that is, one output can be heavily loaded or tied to other outputs without affecting the remaining outputs. Only one of the possibilities is shown.

FIGURE 61. A 50-ohm termination to separate negative voltage. (V_T = −2.0 volts, well bypassed to ground.)

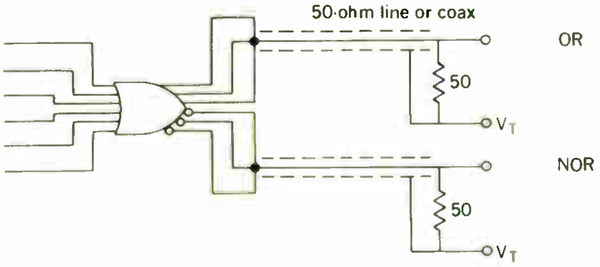


FIGURE 62. ECL gate driving 50-ohm Thévenin equivalent load. Output logic swing ≈ 0.8 volt; typical gate propagation delay = 4.0 ns; typical rise time and fall time at 50-ohm load = 7.0 ns.

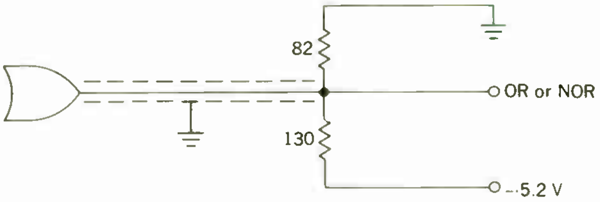
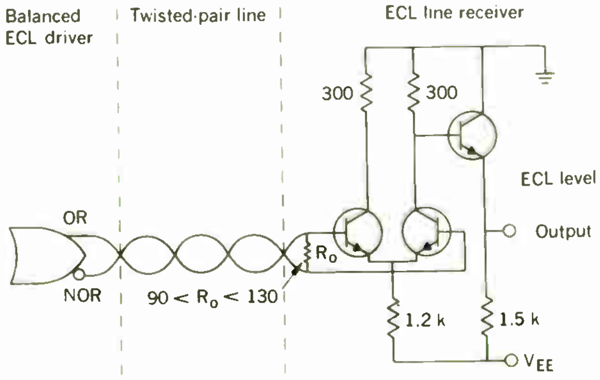


FIGURE 63. ECL balanced twisted-pair driver–receiver.



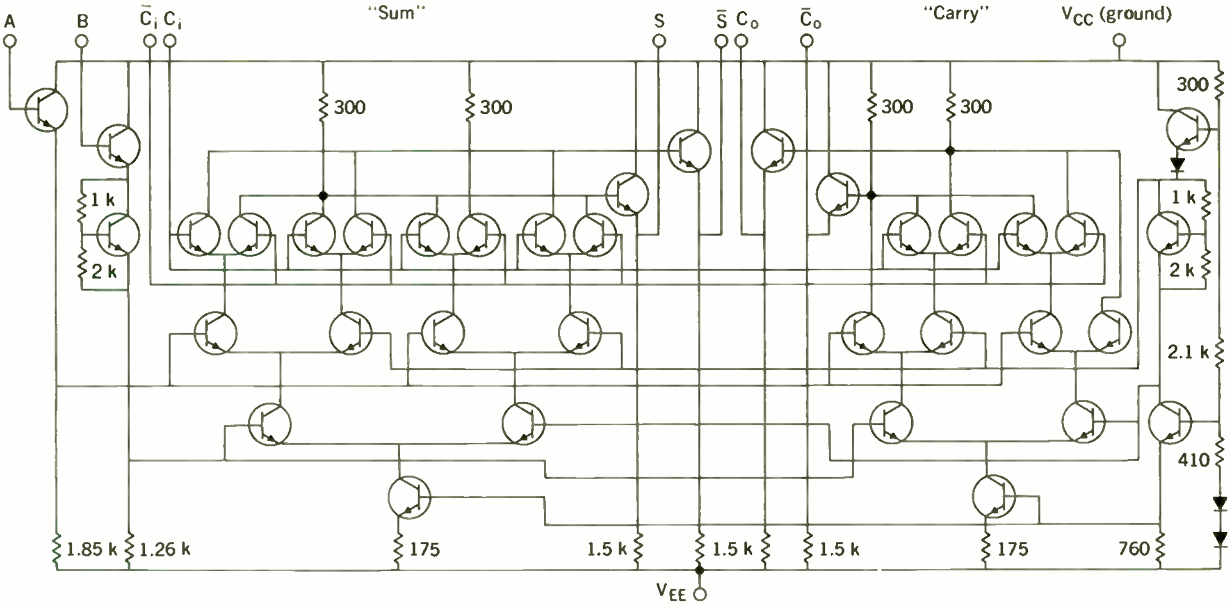


FIGURE 64. ECL full adder.

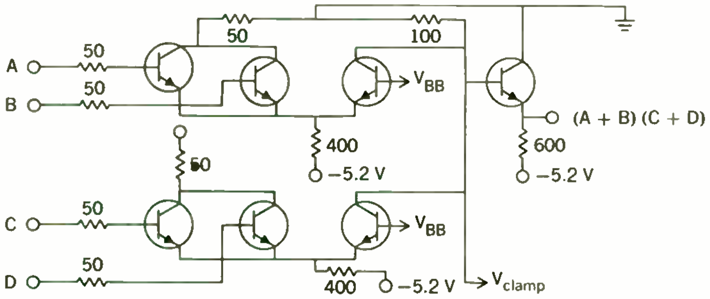
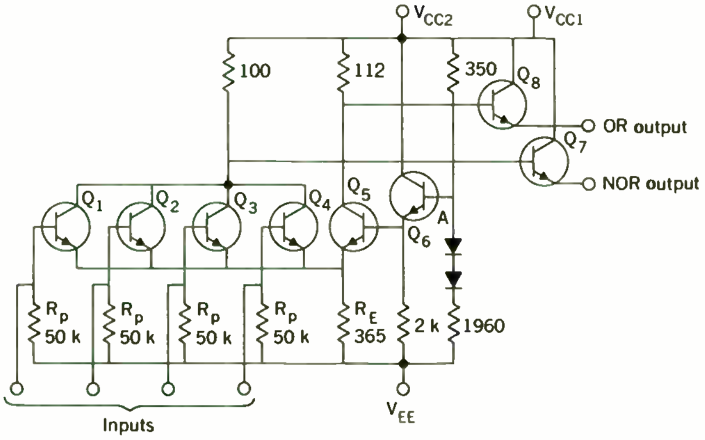


FIGURE 65. A 2-ns ECL OR/AND gate.

FIGURE 66. A 1-ns ECL OR/NOR gate. V_{BB} (point A) = −1.3 volts; V_{CC1} = V_{CC2} = ground; V_{EE} = −5.2 volts; for low-impedance input option, R_p = 2 kΩ.



the circuit design of a 1-ns OR/NOR gate with the capability of driving 50-ohm lines.

The input pull-down resistor R_p on each gate input allows the user to leave the input leads unterminated without noise pickup problems. The 50-kΩ (nominal) resistor is a negligible load to a low-impedance line but is more than sufficient to pull a transistor base to a low level under worst-case conditions. The high values of the resistors are obtained in a small area by using "pinch resistors." A pinch resistor is obtained by diffusing an n-region on top of the p-type resistor, causing the cross-sectional area of the resistor to be greatly reduced, thus increasing resistance. It is possible to leave the "pinch" out of the resistor, in which case it is equivalent to a standard 2-kΩ resistor. The 2-kΩ resistor prevents increased delay times for short lines by providing sufficient pull-down current for line capacitance and gate input capacitance, as illustrated in Fig. 67.

In the schematic diagram another difference is noted from that seen for slower ECL. The V_{CC} or ground supplies are split apart for the basic gate and the emitter-follower outputs. Each output when terminated down to 50 ohms can supply 25 mA of current at a rise time approaching 1 ns. The two different supply leads prevent this current surge from causing an inductive voltage drop to be fed back into the gate. The two supply leads are connected to the ground plane close to the IC package. Transfer characteristics are similar to those of slower ECL, as can be seen in Fig. 68.

ECL speeds of 1 ns require strip-line or at least microstrip-line techniques; therefore, a few words are in order concerning methods of termination. Figure 69 illustrates the normal means for driving multiple gates or a number of gates spread along a transmission line.

Series termination has the advantage of no additional power dissipation, but only one or two gates can be connected to the far end of the line. A gate connected elsewhere on the line sees only half amplitude until static conditions prevail; see Fig. 70.

An interesting and effective method for driving multi-

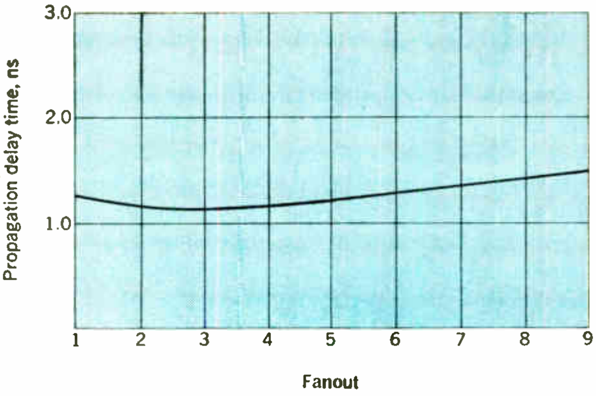
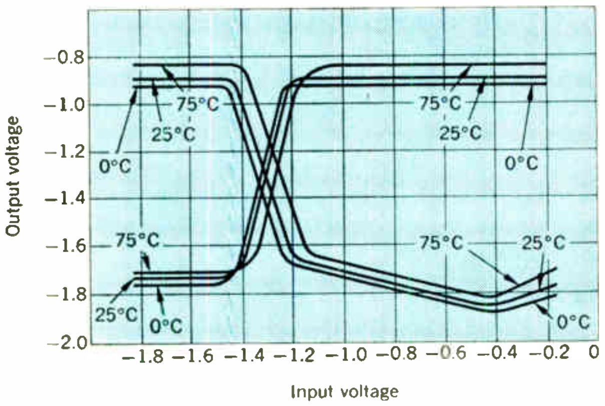


FIGURE 67. Average propagation delay time vs. fanout. Because of dc loading, a maximum of ten 2-kΩ pull-downs is recommended. For worst-case design a maximum fanout of 8 allows for maximum diffused-resistor variations.

FIGURE 68. Transfer characteristics for higher-speed ECL (load of 50 ohms to −2.0 volts). Although there is a similarity to curves for slower ECL, V_{BB} has been moved more negative to −1.3 volts to center the switching point. Note how V_{OH} is more negative due to heavy loading of the emitter follower. The saturation break point has moved more negative because of current densities.



ple-terminated lines from one high-speed gate has been developed by Dr. O. Anthony Horna of Comsat Laboratories. A pair of Schottky diodes connected in parallel form an effective nonlinear end-of-line termination to a V_{BB} level. Diode impedance is high until a forward drop of about 350 mV is reached, at which point the diode starts to turn on. With a forward drop of 0.4 volt the impedance decreases to a few tens of ohms. The far end of the driven line appears open-circuited until a reflection reaches the clamping level (V_{BB} ± a Schottky drop). At this point the Schottky diode effectively terminates the line without reflections. Since the Schottky diode turns on in a few hundred picoseconds or less, there is negligible overshoot. Figure 71 illustrates this method of terminating multiple lines, which works very well on impedances down to 90 ohms. As Schottky diodes with lower forward impedance are developed, line impedances down to 50 ohms will work well. The ECL driving gate requires a pull-down resistor on the output of sufficient value to discharge the lines on a negative-going transition.

Low-impedance terminations allow rapid discharge of load capacitance that has been lumped into one area. Figure 72 illustrates delay versus load capacitance.

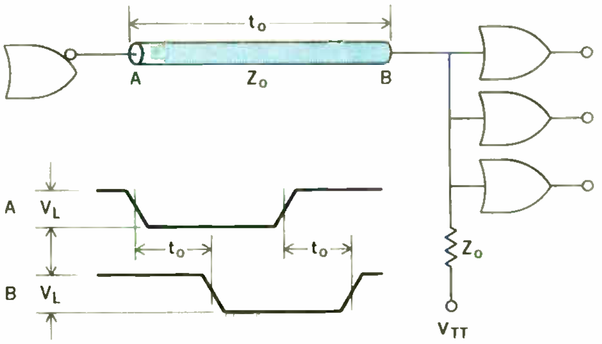
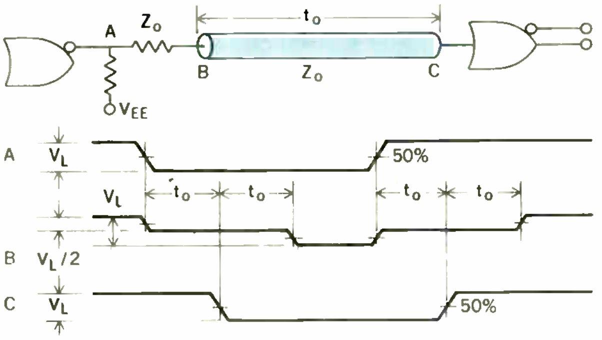


FIGURE 69. Driving a parallel-terminated line. This method is most effective for driving a large number of gates from a single gate. The distributed capacitance of the gate inputs tends to lower the characteristic impedance of the transmission line.

FIGURE 70. Driving a series-terminated line. The far end of the line must be essentially open-circuited (high impedance) to obtain full ac amplitude; therefore, a fanout of 1 is normally used. Higher fanouts reduce the available logic swing until after dc conditions prevail.



Layout guidelines for 1-ns ECL

Power-supply guidelines. Power-supply ripple on the −5.2-volt line should be kept less than 50 mV, and regulation of 10 percent or better is recommended. Every five to ten IC packages should be decoupled, depending upon the printed circuit board layout. Disk ceramic RF-type capacitors are recommended, with leads as short as possible. Values of 0.01 μF to 0.1 μF are effective. A ground plane is recommended, especially for large boards.

Multilayer PC boards. Multilayer boards are desirable in order to control strip-line impedances, as well as to provide good decoupling and a low-resistance ground plane. Small two-layer boards may be used if sufficient care is taken to provide a good ground-plane environment.

Point-to-point wiring and termination. Open wiring is limited to about 2.5 cm or less. Severe ringing occurs beyond this length. Strip transmission lines are suitable for interconnection between devices. The best results are usually achieved with 50-ohm lines; they should be kept reasonably short and as wide as possible (while maintaining correct impedance). This minimizes signal degradation. For example, a 0.5-mm-wide, 50-ohm strip line, 25 cm long, has an inherent rise time of about 200 ps.

A decrease in line width or increase in length increases degradation (because of the added series resistance).

Best results are usually obtained by using transmission lines with parallel terminations, where the terminating resistor is at the end of the driven line.

Fanout considerations. For high fanout (6 to 8), 50-ohm lines are the most desirable. When possible, fanout should be lumped at the end of a transmission line. Although distributed fanout along a transmission line is possible, it should be kept to a total length of less than about 13 cm. Distributed fanout can cause transmission-line reflections in the area of the transition region due to gate inputs unhooking from the line. For the low-Z input devices the delays are estimated by adding $C_{stray} \leq 1.7$ pF per fanout node. This C_{stray} is normally attributed to printed-circuit line capacitance. When line lengths are less than 3.8 cm it is best to use high-impedance printed lines. If low-Z input parts are used with line lengths greater than 3.8 cm, low-impedance terminated strip lines must be used (if a 25-mA load current is not exceeded).

A termination of 50 ohms to V_{EE} may be used with 50-ohm strip lines where lengths are less than about 5 cm. Otherwise, the termination should be 50 ohms to −2.0 volts. A single 50-ohm-resistor termination requires another power supply but has the advantage of saving power. A Thévenin equivalent termination saves the use of another power supply but consumes more power than the single-resistor termination. Line stubs from the transmission line without terminations should be kept to 1.3 cm or less to prevent reflections.

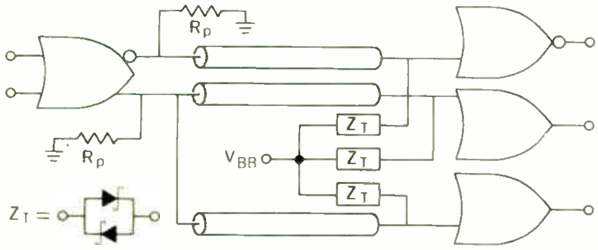
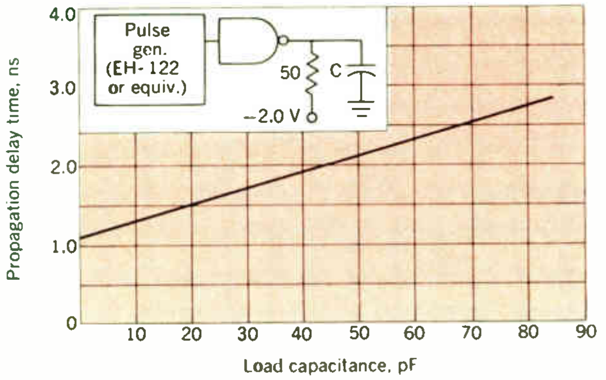


FIGURE 71. Driving multiple 90-ohm lines. Z_T = two Schottky diodes in parallel ($Z_{on} \approx 50$ ohms, $V_f \approx 0.4$ volt). The Schottky diodes provide an ideal termination because of the low forward impedance, which effectively terminates the line. The load current from the ECL output is only a few milliamperes plus the current through R_p.

FIGURE 72. Average propagation delay time vs. load capacitance. The flatness of the curve is attributable to the low terminating impedance. The increase in propagation delay is as expected because of the RC time constant. Thus the 1-ns ECL is ideal for driving the high capacitance associated with multilayer printed circuit cards.



Crosstalk between printed circuit conductors. The crosstalk level is approximately 5 percent for 0.38-mm-wide 50-ohm lines. Line separation does not radically affect crosstalk, which is attributable more to the presence of plated-through holes and open areas in the ground plane.

For "implied OR" circuits, maximum separation of emitters should be about 4 cm. Typically, propagation delay increases 50 ps per additional emitter.

Circuit advantages and disadvantages

The high speed of ECL and the differential-amplifier nature of the input circuitry permit the construction of superior comparator functions. Therefore, ECL will become widely used for high-speed analog-to-digital conversion. Also, the capability of series gating and the switching of current sources will permit economical majority and threshold logic with various input weights.

ECL lends itself well to logic arrays and LSI because of the logic flexibility of the basic gate. Excellent speed–power products have been obtained as a result of the low-capacitance loading internal to an array. ECL usage in arrays and large custom functions will increase rapidly.

No family of logic is universal, however, and ECL does have its drawbacks. The nonconventional logic levels are difficult to interface with discrete devices and other logic thus requiring separate translators. Due to high bandwidths and a worst-case noise immunity of about 200 mV, more care in shielding from external noise sources must be taken. Also, fall time increases significantly with capacitive loading unless additional terminating resistors are employed.

ECL disadvantages

1. Power dissipation tends to be higher than low-level saturated logic
2. External noise immunity is lower than some saturated logic
3. Translators are required for interfacing with saturated logic
4. ECL slows down with heavy capacitive loading

Advantages

1. Highest-speed logic available
2. Low to medium cost
3. Low output impedance
4. High fanout capabilities
5. Constant supply current versus frequency and logic state
6. Very low noise generation
7. Complementary outputs save package count
8. Low crosstalk between signal leads
9. All outputs are buffered
10. Outputs can be tied together, giving the "implied OR" function
11. Common-mode rejection of noise and supply variations is 1 volt or greater
12. Bias supplies are internal, resulting in a single power supply
13. Minimal degradation of parameters with temperature variations
14. Large family of devices yields economical designs
15. Power dissipation can be reduced through use of implied OR and the series gating technique

16. Easy data transmission over long distances by the use of the balanced twisted-pair technique with standard parts
17. Constant noise immunity versus temperature
18. Best speed–power product available
19. All positive logic functions are available
20. Adapts easily to MSI and LSI techniques

Areas of application

1. Instrumentation
2. High-speed counters
3. Computers
4. Medical electronics
5. Military systems
6. Large real-time computers
7. Aerospace and communication satellite systems
8. Ground support systems
9. High-speed A/D
10. Digital communication systems
11. Data transmission (twisted pair)
12. Frequency synthesizers
13. Phased-array radar
14. High-speed memories

Predictions

Emitter-coupled logic—because of its flexibility, high speed, and excellent speed–power product—will continue to grow in usage and be a major form of logic by the mid-'70s. The writer believes that by 1975 the ECL dollar volume will be larger than that for any other logic form employed in new designs. In support of this statement, most major computer manufacturers already use ECL and the growing digital communications and instrumentation markets are rapidly trending to high speed.

P-channel MOS

Metal oxide semiconductor (MOS) devices are becoming significant in the industry and exhibit a very good growth rate. Because of easy processing, the p-channel device shown in Fig. 73 is the most popular. A negative potential on the gate causes the silicon to invert under the gate, allowing hole conduction. The device acts like a variable resistor, modulated in value by the gate voltage. The source-to-drain impedance looks like a resistor for low source-to-drain voltages; however, for higher voltages the P-MOS device reaches the current saturation region and source-to-drain current becomes relatively constant. An MOS device operating in this region makes an ideal load for a P-MOS gate.

The voltage threshold at which the device turns on can be varied by changing the gate insulating material, dielectric thickness, and crystal orientation of the silicon. Note how the metal overlaps the p-diffused regions, adding to device capacitance. The "on resistance" of an MOS device at a given gate voltage can be varied by changing the length-to-width ratio of the device—that is, changing the geometry. Normal "on resistances" are generally several thousand ohms. P-MOS devices have thresholds of approximately 4 volts down to 2 volts, depending upon the processing techniques used. Newer technologies are permitting higher-performance devices. Silicon nitride dielectric permits thinner gate insulation for a given breakdown voltage and lower thresholds. Self-aligning gate structures, such as those used in silicon gate technology, lower both thresholds and Miller capacitance, thus increasing performance by a factor of about five. Thin dielectric under the gate is desirable from a threshold and device gain point of view, but the thinner the oxide, the easier it is to rupture the oxide with a voltage transient. In the early days of MOS technology, devices failed because static discharge easily ruptured the gate oxide. Common practice is now to protect the MOS gate with a reverse-biased diode that will break down before the gate oxide ruptures. However, some caution is still in order since the amount of energy that can be dissipated without damage is limited. Usually the diodes are eliminated from the circuit schematic because protection diodes have no effect under normal operating conditions except to increase input capacitance.

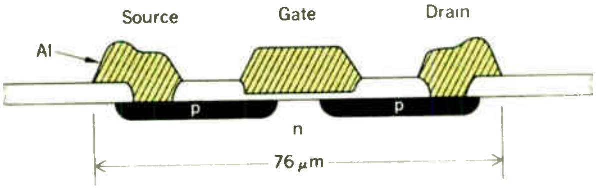
The basic four-input P-MOS gate (Figs. 74 and 75) performs the NAND logic function but is frequently referred to as a NOR gate, using the negative logic terminology where a low level is taken as true. The lower MOS device in Fig. 74 acts as a constant-current resistor. Only when all inputs *A* through *D* are high will the output become low and perform the NAND logic function.

Input impedance is essentially capacitive (an open circuit for dc) and, therefore, no input characteristics will be shown. The output characteristics are basically resistive. For each device that is turned on (negative input on the gate), there is about 2-kΩ resistance to ground. If all devices are off, the impedance is about 25 kΩ to V_{DD}. The V_{GG} potential is negative enough to keep the "load" MOS device well turned on, even as the output voltage goes low and approaches V_{DD}. If V_{GG} and V_{DD} were the same potential, the output impedance would become very high. This higher impedance would further slow down operating speeds because of *RC* time constants.

Transfer characteristics of the p-channel MOS gate will vary with processing, but will look similar to those shown in Fig. 76. Note that the sharp transitions of bipolar circuits are absent. In other words, MOS devices do not exhibit high voltage gain and narrow transition regions. Moreover, transfer characteristics will vary widely depending upon external loading (due to relatively high output impedance). As devices with lower threshold voltages are made, the transfer characteristics become sharper, showing a higher voltage gain.

P-MOS design results in small devices (only one diffusion is required). Gates and basic logic circuits have not become very popular because there is a lack of drive capability unless large-geometry devices are employed. Large, complex, repetitive functions, such as long shift registers and high-capacity memories, have proved very practical, however. In these functions there are relatively few outputs in relation to the total logic complexity. This arrangement provides for inexpensive interfacing on a per-function basis and permits easy use in systems

FIGURE 73. Typical p-channel MOS device.



with bipolar logic. Since P-MOS permits high-density circuitry, it is a natural tool for products of the LSI complexity level. Circuits of this complexity tend by nature to be unique to a given application rather than of wide general use, and this volume is unfortunately low and unit costs are high. Computer-aided design techniques are helping to keep costs and design time to a minimum for these types of "custom" circuits. However, costs per gate in custom circuits will remain higher than in the more universal circuits, such as memories and shift registers. Industry projections indicate that a larger percentage of the total P-MOS market will go toward standard-type circuitry, such as memories, in the future. P-MOS will remain the best technology for this area so long as high speed is not an important factor. When the MOS device is turned on, current can pass in either direction. As in a conventional switch, this capability lends itself to some circuits not possible with bipolar techniques (usually resulting in fewer components). P-MOS also finds use in multiplexers handling analog signals.

P-MOS disadvantages

1. Processing must be done with more care than with bipolar, since the devices are surface-sensitive
2. Devices must be handled more carefully than bipolar devices since excessive static electricity can "zap" the narrow gate oxide, even with internal breakdown diode input protection
3. High output impedance limits driving capabilities
4. Operating speed is usually limited to a maximum of a few megahertz
5. Two power supplies are usually required

Advantages

1. Simple processing permits fast turnaround times
2. Processing yields can be good even for large die
3. High-circuit density allows more logic per given area than with other semiconductor techniques
4. High input impedance allows very high fanout where speed is not a consideration
5. Bidirectional devices give more flexibility to the circuit designer
6. P-MOS technology results in the lowest cost per bit for memories and long shift registers

Areas of application

1. Small computers and peripherals
2. High-density solid-state memories
3. Calculators
4. Serial storage and recirculating memories
5. Multiplexers
6. Frequency dividers
7. Communications

CMOS

Complementary metal oxide semiconductor (CMOS) technology employs both p-channel and n-channel devices on the same silicon substrate. Both types are enhancement-mode devices; that is, gate voltage must be increased in the direction that inverts the surface in order for the device to conduct. An enhancement-mode device is normally turned off. Figure 77 illustrates the basic construction of CMOS. The crosshatched lines represent aluminum metal, which interconnects the devices. It is seen that the n-channel and p-channel devices are connected in series. Only one device is turned on at a time, resulting in extremely low power dissipation. Dissipation is primarily from the switching of devices through the active region and the charging and discharging capacitances. The basic gate is shown in Figs. 78 and 79. As shown in Figs. 80 and 81, n- and p-channel devices may be interchanged to form a positive logic NAND gate. Due to the symmetry of the devices and MOS construction, either a positive or negative supply may be used. CMOS design allows operation from +4.5 volts to +16 volts on V_{DD}, with +10 volts nominal. Transfer characteristics change slightly depending upon which or

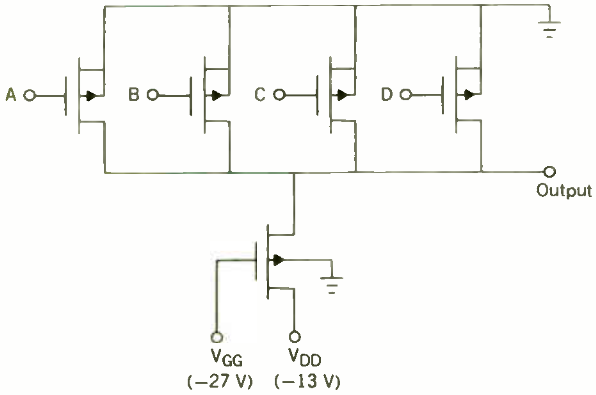


FIGURE 74. Basic four-input high-threshold P-MOS gate. (Threshold voltage ≈ 4 volts.)

FIGURE 75. Logic symbols for basic P-MOS gate.

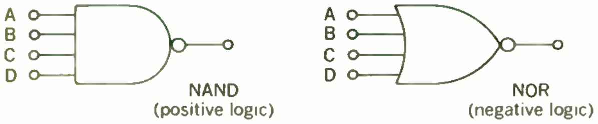
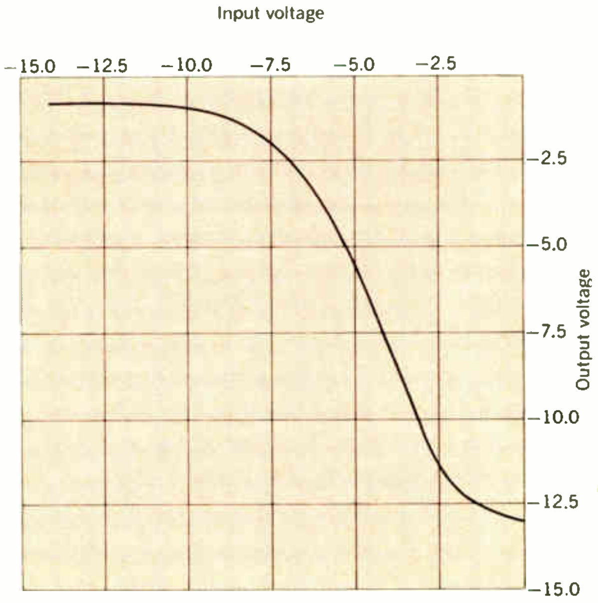


FIGURE 76. Transfer characteristics for typical high-threshold p-channel MOS gate.



how many inputs are activated. Thresholds remain roughly in the center of the logic swing (Fig. 82).

Another advantage of CMOS is that as one device is turning on, the other device is increasing its impedance. A push–pull effect that takes place narrows the transition region, giving sharper transfer characteristics. The p-channel devices have the substrate connected to the most positive circuit potential (V_{DD}) whereas the n-channel devices have the p-region connected to the most negative potential (usually ground).

A power dissipation vs. frequency plot has been made for a typical CMOS flip-flop. Note the extremely low power dissipation at low frequency even with elevated supply voltage, as shown in Fig. 83.

CMOS advantages are obvious and this technology will find wide application as more devices and manufacturers become available.

CMOS disadvantages

1. Chip size is not as small as P-MOS
2. Since output impedance is high, the interfacing capabilities are restricted
3. More complex processing is required

Advantages

1. Low power dissipation (especially at low duty cycles)
2. Good noise immunity, typically ≈ 45 percent of V_{DD}
3. Very wide power-supply variations allowed
4. Full temperature-range capabilities
5. High fanout to other CMOS
6. Large logic swing from V_{DD} to ground (no external loading)
7. Propagation delay faster than P-MOS (about 50 ns)

Areas of application

1. Battery-operated equipment
2. Noisy environments
3. Aerospace logic systems
4. Portable digital communications equipment
5. Industrial electronics

Comparing the IC logic families

The digital IC families tend to go through the typical marketing cycle of growth, maturity, and decline, which is illustrated in Fig. 84. Note that even though a family such as RTL is losing its percentage of the total market, shipments have been growing over the past few years.

Much information has been covered on the various needs of the logic and systems designer with extensive material presented on the various major logic families. The basic gate in each family sets the major family traits and has been studied extensively. It is now useful to sum up these characteristics or parameters in chart form for easy comparison. Table II summarizes parameters for the seven major families and also subfamilies for RTL, TTL, and ECL. Fifteen categories of comparison have been chosen:

1. *Circuit form* simply refers to the type of devices and components utilized in the circuit design. This row serves as a convenient mnemonic help in linking circuit design to other parameters.

2. *Positive logic function of the basic gate* refers to the logic function implemented by the basic circuit in the family. MIL-STD-806B terminology is used, where the most positive (or least negative) voltage level is taken as a high level, which is defined as true.

3. *Wired positive logic function* refers to whether or not there is the capability of performing additional logic by tying outputs together. This is not possible with TTL because of the output circuit design, but the A-O-I circuit modification increases flexibility and essentially is equivalent to the "implied AND," as found in DTL.

4. *Typical high-level output impedance* is a measure of circuit drive capability. It can be used to determine expected rise times for a given amount of capacitive loading. Moreover, high-level noise immunity is greatly improved, from an energy point of view, if output impedance is low.

5. *Typical low-level output impedance* is, for saturation logic, the saturation resistance of the transistor measured in the range of normal load currents. The value is usually

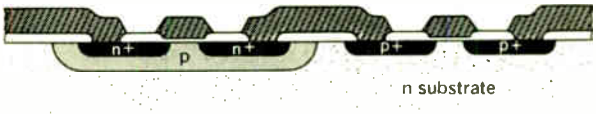


FIGURE 77. CMOS construction.

FIGURE 78. Basic dual CMOS four-input gate.

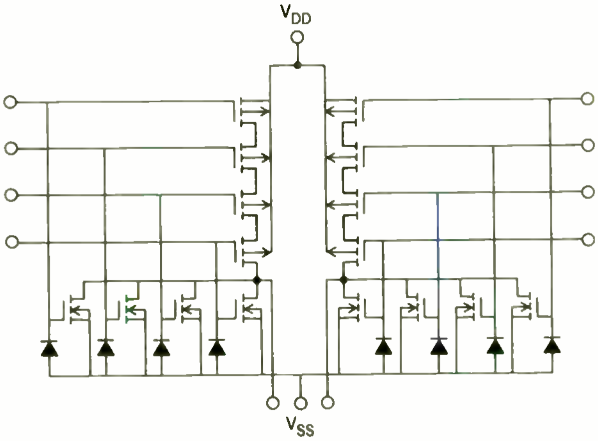


FIGURE 79. Dual four-input NOR logic symbol.

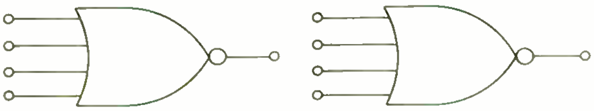
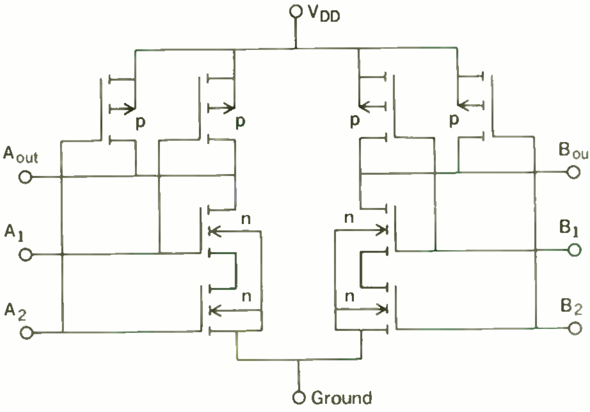


FIGURE 80. Dual CMOS two-input NAND gate.



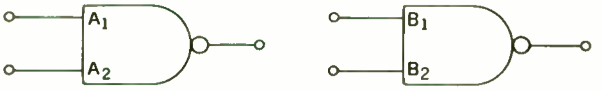
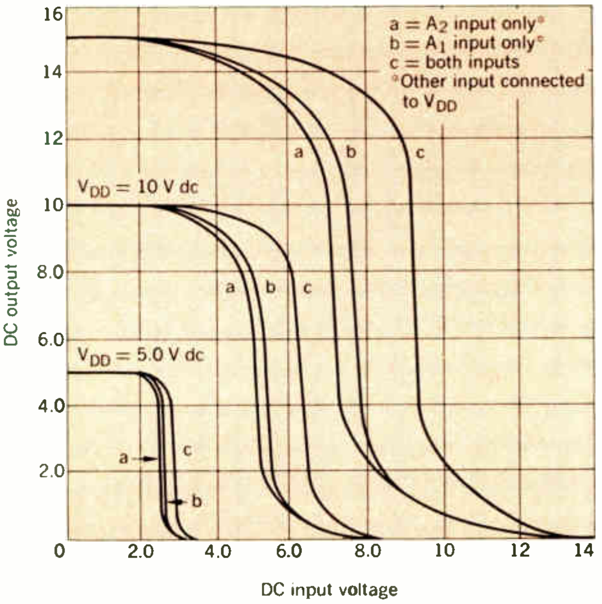


FIGURE 81. Dual two-input NAND logic symbol.

FIGURE 82. Typical CMOS transfer characteristics. The a, b, c curves refer to the dual two-input NAND shown in Fig. 80. Input impedance is about 10^{12} ohms (essentially an open circuit). Output impedance 1.5 kΩ at a 10-volt supply voltage.



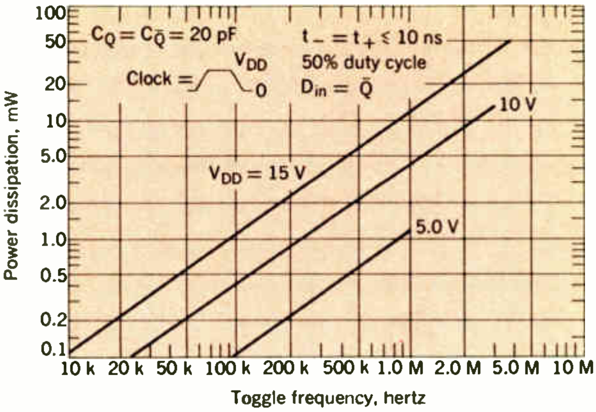
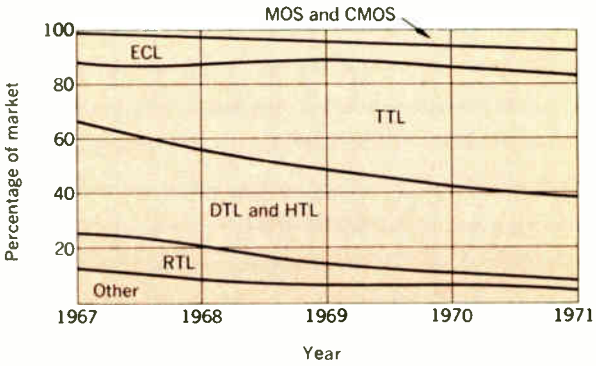


FIGURE 83. Power dissipation as a function of frequency for a typical CMOS flip-flop.

FIGURE 84. Digital IC families as percentages of the market. (Source: EIA, plus Motorola projections.)



in the range of 10 to 30 ohms. ECL exhibits very low output impedance unless the emitter follower is turned off by forcing the emitter node to a higher voltage level. Under these conditions, the output resembles a fixed-value current sink, the value of which is listed in the chart.

6. *Fanout* is simply a worst-case specified ratio of output drive capabilities divided by input loading. It signifies worst-case number of inputs that an output can talk to. Actual values may vary from the chart listing, depending upon the particular manufacturer.

7. *Specified temperature range* refers to the range or ranges of ambient temperature over which the family is specified for operation within given limits. For silicon devices the maximum allowable junction temperature is normally 175°C for an all-aluminum metalization system. Since temperature effects tend to degrade circuit performance, devices specified over the full military temperature range (−55° to 125°C) are normally selected to tighter criterions, thus increasing costs.

8. *Supply voltage* is self-explanatory. Operation outside of these limits usually degrades performance, such as speed and fanout.

9. *Typical power dissipation per gate* is a parameter that is good only for a first-order approximation when dissipation between families is compared. The judicious use of complex functions, implied AND, and implied OR can reduce total system power dissipation by one half. Moreover, temperature and frequency of operation often affect total power dissipation.

10. *Immunity to external noise* is listed in relative terms, since noise energy, not voltage, causes problems in a logic circuit. Because of its ease of measurement only voltage-noise immunity is specified by manufacturers.

11. *Noise generation* is also listed in general terms due to the difficulty of testing and variations that occur due to circuit environment. Noise generation affects costs due to differences in capacitive bypassing requirements, printed circuit card layout restrictions, and wiring restrictions.

12. *Typical propagation delay per gate* is the average (not worst-case) delay time that would be expected in a circuit where a nominal fanout is employed. Large fanouts and heavy loading increase circuit delays. Also, these times do not include wiring delays, which are usually around half the speed of light—that is, 1 ns per 15 cm.

13. *Typical clock rate for flip-flops* refers to the maximum frequency at which typical devices will operate. The frequency range covers the different designs that are available in some families. The actual clock rate of a system is usually from one half to one tenth the frequency listed. Toggle rates are shown in the chart and may be faster than shift rates, depending upon the device design.

14. *Number of functions and family growth rate* is a very important category to most designers. The greater the number of functions in a family, the fewer will be the number of packages required to implement a typical system design. The net result is usually a reduction in

II. Comparison chart of the major IC digital logic families

Parameters	RTL	Low-Power RTL	DTL	HTL	12-ns TTL	6-ns TTL	4-ns ECL	2-ns ECL	1-ns ECL	P-MOS	CMOS
1. Circuit form	← resistor–transistor →		diode–transistor	diode–Zener transistor	← transistor–transistor →		← emitter-coupled current mode →			p-channel MOS	complementary MOS
2. Positive logic function of basic gate	← NOR →		← NAND →				← OR/NOR →			NAND	NOR or NAND
3. Wired positive logic function	← implied AND → (some functions)		implied AND	implied AND (A-O-I)	← AND-OR-INVERT →		← implied OR → (all functions)			← none →	
4. Typical high-level Z_o, ohms	640	3.6 k	6 k or 2 k	15 k or 1.5 k	70	10	15	6	6	2 k	1.5 k
5. Typical low-level Z_o	R_{sat}	R_{sat}	R_{sat}	R_{sat}	R_{sat}	R_{sat}	15 ohms or 2.7 mA	6 ohms or 6.7 mA	6 ohms or 21 mA	25 k	1.5 k
6. Fanout	5	4	8	10	10	10	25	25 inputs or 50 ohms	10 low-Z inputs or 50 ohms	20	50 or higher
7. Specified temperature range, °C	−55 to 125 0 to 75 15 to 55	−55 to 125 0 to 75 15 to 55	−55 to 125 0 to 75	−30 to 75	−55 to 125 0 to 70	−55 to 125 0 to 75	−55 to 125 0 to 75	−55 to 125 0 to 75	0 to 75	−55 to 125 0 to 75	−55 to 125
8. Supply voltage	3.0 V ± 10% 3.6 V ± 10%	3.0 V ± 10% 3.6 V ± 10%	5.0 V ± 10%	15 ± 1 V	5.0 V ± 10% 5.0 V ± 5%	5.0 V ± 10% 5.0 V ± 5%	−5.2 V + 20% − 10%	−5.2 V + 20% − 10%	−5.2 V ± 10%	−27 ± 2 V −13 ± 1 V	4.5 to 16 V
9. Typical power dissipation per gate	12 mW	2.5 mW	8 mW or 12 mW	55 mW	12 mW	22 mW	40 mW	55 mW plus load	55 mW plus load	0.2 to 10 mW	0.01 mW static ≈1 mW at 1 MHz
10. Immunity to external noise	nominal	fair	good	excellent	very good	very good	good	good	good	nominal	very good
11. Noise generation	medium	low–medium	medium	medium	medium–high	high	low	low–medium	medium	medium	low–medium
12. Propagation delay per gate, ns	12	27	30	90	12	6	4	2	1	300	70
13. Typical clock rate for flip-flops, MHz	8	2.5	12 to 30	4	15 to 30	30 to 60	60 to 120	200	400	2	5
14. Number of functions; family growth rate	high; growing	high; growing	fairly high; new functions in TTL	nominal; growing	very high; growing	very high; growing	high; growing	high; growing	high; growing	low; growing	low; growing
15. Cost per function	low	low	low	medium	low	medium	low	medium	high	medium to high	medium to high

III. Availability of functions for various IC families

	RTL	DTL	HTL	TTL	ECL	MOS	CMOS
Gates:							
AND	X	X		X	X		
NAND	X	X	X	X	X	X	X
OR	X	X		X	X		
NOR	X	X		X	X		X
Exclusive OR	X	X	X	X	X		X
Exclusive NOR	X			X	X		
OR/NOR	X				X		
A-O-I		X	X	X			
Inverters	X	X	X	X			X
Expanders	X	X	X	X	X		
AND/OR select							X
Flip-flops:							
R-S	X	X	X	X	X		X
Latch	X	X	X	X	X		
"T"	X				X	X	
"D"	X	X		X	X		X
J-K	X	X	X	X	X		
Counters:							
Divide-by-10	X	X	X	X	X		X
Divide-by-12				X			
Divide-by-16	X	X	X	X		X	
Programmable				X			X
Up/down				X		X	
7-stage							X
14-stage							X
Decoders:							
BCD to decimal	X		X	X			
Excess 3 to decimal				X			
BCD to 7 segment				X		X	
4 to 16 lines				X			
3 to 8 lines				X			
2 to 4 lines				X			
Encoders:							
Binary to BCD				X			
BCD to binary				X			
Priority				X			
Drivers and buffers:							
Line drivers		X	X	X	X		
Lamp drivers	X	X	X	X	X		
Clock drivers	X			X	X	X	
Relay drivers			X				
High-fanout buffer	X	X		X	X		X

	RTL	DTL	HTL	TTL	ECL	MOS	CMOS
Arithmetic functions:							
Adder	X			X	X	X	X
Look-ahead carry block				X	X		
Subtractor	X				X		
Magnitude comparator				X			
Arithmetic unit				X	X		
Ripple-through multiplier				X			
Shift registers:							
2-bit		X	X		X		
4-bit	X			X			
8-bit				X			X
Multibit (serial)						X	X
Memories:							
8-bit RAM					X		
16-bit RAM			X	X	X		X
64-bit RAM				X	X	X	X
128-bit ROM				X			
256-bit ROM				X		X	
Large ROM				X		X	
Large serial-access read/write						X	
CAM or CRAM				X	X		
Miscellaneous:							
Multiplexers or data selectors	X			X	X	X	X
Demultiplexers or data distributors				X	X		
Line drivers (differential)	X	X		X	X		
Line receivers (differential)	X	X		X	X		
Translators	X		X		X		
Multivibrators		X	X	X			
One-shot		X	X	X			
Pulse stretcher (retriggerable one-shot)			X	X			
Schmitt trigger	X			X	X		
A/D comparator					X		
Frequency/phase detector				X	X		
VCM (voltage-controlled multivibrator)				X	X		
Parity tree				X	X		
8-bit position scalar				X			
Sense amplifier		X		X	X		
Prescalar					X		
Comparator				X			

both time and cost. Again, relative terms have been used for descriptive purposes. The growth rate indicates whether or not the family still has a future. DTL for example is static, but new compatible functions are being introduced in TTL. Table III summarizes the main types of gates and functions available in the major IC families. This chart is in no way all-inclusive and is intended only as an attempt to bring the reader up to the time of this writing. New functions are being added weekly by the various manufacturers.

15. *Cost per function* is an extremely important consideration. The cost is given on a per-function basis rather than a per-gate basis because of the difficulty in defining a gate in some of the more complex functions. Typical functions include registers, counters, memories, and parity trees. Note that the P-MOS packages are medium to high in cost. Here costs per gate can actually be the lowest, depending upon definitions, since some of the most popular functions are shift registers of several hundred bits in length. System costs should be based upon actual paper studies involving system layout guidelines, logic minimization, the use of wired logic where possible, and other considerations. This procedure prevents decisions based only upon relative gate costs, which are superficial at best.

Conclusion

This article is intended as an in-depth analysis of the needs of the digital designer and the solutions offered by industry in the form of various IC logic families. The rapid rate of introduction of new functions in the families precludes a timely discussion in a formal manner. Also, the thousands of functions available tend to prevent a comparative analysis, except in regard to the basic gate or building block. It is hoped that this article will prove to be a useful contribution to the literature and a desirable source of relative information for the logic and/or system designer.

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World population growth and related technical problems

Man is quickly losing any chance he might have had to control his greatest problem—overwhelming population growth—and still maintain a high quality of life

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Although most literature concerning world population growth and allied problems has been written for a wide spectrum of readers, the present article provides data related to population growth, energy consumption, and life-support capabilities in a format designed specifically to satisfy the technologist. Momentous technical advances have occurred during the last century, but it has become evident that concomitant penalties are beginning to appear. If such a rate of technical growth continues into the future, social systems will become more and more complex, with an increasing probability of malfunction unless closer attention is given to the possible penalties associated with such advances. Since industrialization problems in a highly populated world are difficult, if not impossible, to predict, the intent of this article is to emphasize the need for engineers and scientists to become aware of the importance of their work, and to stimulate thought regarding the relationship between technology and the ultimate quality of life.

During the last decade, considerable attention has been given to predictions regarding future world conditions resulting from world population growth and the environmental effects of accompanying industrialization. Although warnings have been issued by rational and informed writers, a number of equally informed writers have just as firmly stated that not only will technology solve each crisis, but that the quality of life will continue to improve. The controversy has reached worldwide dimensions, with many of the facts clouded by emotional debate.

At this time, no certain conclusions can be drawn; nevertheless, it is possible to examine some fundamental characteristics of the world as a system and attempt some reasonable predictions based on an objective technical analysis of developing trends.

Population dynamics

The most basic assumption made in the following discussion is that world conditions are directly influenced by human population levels. This concept was first introduced in 1798 by Thomas Malthus, who proposed that population tends to increase geometrically whereas food supplies increase only arithmetically. He predicted only disaster since population would increase faster than food supplies until limited by war, famine, disease, and a general breakdown of law and order.

He was wrong; disaster has not occurred. Consequently, he has been held up ever since as an object lesson to those who would predict population on the basis of existing data. His principles and reasoning were sound, however, and his extrapolations suffered only from lack of knowledge of the potentialities of technology. Even though he lived prior to the industrial revolution and could not possibly have foreseen the advances that followed, he is still used today as an argument against current attempts to predict population levels and future world conditions.

We now have about 170 years of additional knowledge as well as good population data from the year 1900, and hence are able to look a little further into the future than Malthus could. Human population growth, however, is an extremely complex phenomenon, and analysis involves knowledge gathered from all scientific fields. The overwhelming importance of population growth and its effects demands that any evaluation of trends be as objective as possible. Since several attempts have been made to predict population growth, we will first discuss the rationale behind them.

Initial population growth—the exponential law. If a small population is introduced into a virgin environment, the growth occurs initially at a rate proportional to the current population; i.e.,

$$\frac{dN}{dt} = (b - d)N = rN \tag{1}$$

where N = population size, b = birth rate, d = death rate, and $r = (b - d)$ = fertility rate.

When population size is small, the fertility rate is constant, and the solution is simply the familiar form

$$N = N_0 e^{r(t - t_0)} \tag{2}$$

where N_0 is the initial population at some initial time t_0. This result has been checked experimentally for closed systems of various species, and has been found valid for low populations. It is of interest to note that (2) is used to calculate population doubling times even for high populations. Let $N/N_0 = 2$, and solve for the doubling time,

$(t_2 - t_0) = T_2 = 0.693/r$. The present world fertility rate is about 1.9 percent, which gives a population doubling time of 37 years.

High-density growth—the logistics growth law. After some growth period, the population increases to a high enough level significantly to affect food supplies and other resources needed for life support. During the latter stages of growth, environmental resistance becomes the dominant growth inhibitor and tends to limit population size to some upper bound. In 1924, Pearl and Reed,[1] in studies of fruit flies in a closed ecological system, noted that the population growth followed a fairly regular S-shaped curve. This led them to postulate the logistics growth law:

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{M}\right) \tag{3}$$

where r is constant, M is the upper bound on population, and the parenthetical term represents the action of environmental resistance; i.e., as $N \rightarrow M$, the growth rate approaches zero. The solution to (3) is

$$\frac{N}{N_0} = \frac{e^{r(t-t_0)}}{1 - (N_0/M)[1 - e^{r(t-t_0)}]} \tag{4}$$

which, of course, has the S shape when plotted. Differentiating Eq. (3) once with respect to time, and equating the result to zero, we find that the maximum slope occurs when $N/M = \frac{1}{2}$. This result implies that the upper bound can easily be predicted by simply observing current population growth rates. When the growth rate passes through a maximum, the upper bound is obtained by simply doubling the population at that time.

Pearl and Reed attempted to use the logistics law to predict human population growth by curve-fitting Eq. (4) to existing 1924 population data for several countries in order to predict upper bounds. A retrospective examination of the authors' results by comparing post-1924 data with their predictions reveals that the logistics law is grossly in error. For example, the predicted upper bound for world population was 2 billion. The present world population is about 3.4 billion and continues to increase. Since neither the exponential nor the logistics concept can accurately predict human growth, the interesting biological fact is implied that human growth behavior differs widely from that of any other plant or animal for large population sizes.

The coalition law. In order to characterize human growth better, von Foerster *et al.*[2] proposed a new concept in 1958 to account for the unique behavior of humans. They postulated that since humans possess an effective system of communication, they are able to form coalitions until all elements are strongly linked. This coalition proceeds until the population as a whole can be considered as acting as a single element, or "person," engaged in a gigantic game with nature as the opponent. This is evidenced by such phenomenons as urbanization, industrialization, medical technology, etc. The overall result is that death rates have decreased faster than birth rates. Hence, the authors concluded that the fertility rate r is not constant, but instead is a slowly increasing function of N; i.e.,

$$r = aN^{1/k} \qquad k \leq 1 \tag{5}$$

Substituting Eq. (5) into Eq. (1), the coalition law then becomes

$$\frac{dN}{dt} = aN^{(1+1/k)} \tag{6}$$

Integration from N_0, t_0 to N, t gives the solution directly. Hence,

$$N = N_0\left[\frac{t_d - t_0}{t_d - t}\right]^k \tag{7}$$

where $$t_d = \frac{k}{a}N_0^{-1/k} + t_0$$

Note that as $t \rightarrow t_d$, $N \rightarrow \infty$. Hence, t_d was given the name "doom time"—the period when, theoretically at least, world population will grow unbounded and approach infinity. From a measure of a, k, N_0, and t_0, the doom time can be readily calculated. This was done by a least-squares fit of (7) to world population data as well as estimates from zero A.D. to 1958. The result gives a $t_d = 2027 \pm 5.5$ years, with $k = 0.990 \pm 0.009$, and $N_0 = 10^8$ at $t_0 = 0$. Thus, the world population will approach infinity at 2027 A.D. —about 57 years from now. It is interesting to note that, when post-1958 data are plotted on the curve generated by Eq. (7), the result shows that the actual population is growing slightly faster than predicted!

As might be suspected, however, there is a flaw in the reasoning. Since the gestation period is finite, there must be an upper limit to the possible birth rate. Also, there must be some lower bound to the death rate. Hence, the fertility rate cannot grow indefinitely and must stabilize at some time. The interesting question is, when will this happen and under what circumstances? The coalition hypothesis will probably remain valid for about the next 20 years but, as will be shown, environmental resistance factors will develop to change the fertility rate substantially. To account for these factors, we shall attempt to develop a more appropriate hypothesis.

The modified coalition law. In general, population growth rate can be characterized by a series of the form

$$\frac{dN}{dt} = a_1N + a_2N^2 + a_3N^3 + \ldots + a_iN^i$$

where the coefficients a_i could presumably be obtained by fitting past data. This approach, however, does not facilitate physical interpretation of the meaning of each coefficient. Instead, it is more instructive to construct a growth law as a composite of individual phenomenons affecting population growth, and so it is logical to use the concepts just discussed to attempt a more realistic growth equation representing the rather complex behavior of humans.

Since there must be an upper limit to fertility rate, we can modify Eq. (5) to include this effect by defining

$$r = A\left[1 - \exp\left(-\frac{a}{A}N^{1/k}\right)\right] \tag{8}$$

A Taylor series expansion can be used to illustrate that this expression approximates Eq. (5) at low values of N; for high values of N, it implies that the fertility rate approaches the upper bound A.

Even though the logistics hypothesis [Eq. (3)] by itself is not a valid description of human growth, the concept is sound since there must be some upper limit to the earth's life-support capacities—and thus the logistics concept must be implicit in any realistic prediction. Combining Eq. (8) with Eq. (3) results in a growth equation that accounts for effects of both environmental resistance and the coalition characteristic of human behavior; i.e.,

$$\frac{dN}{dt} = A\left[1 - \exp\left(-\frac{a}{A}N^{1/k}\right)\right]\left[1 - \frac{N}{M}\right]N \qquad (9)$$

Since this equation cannot be integrated for any arbitrary values of the constants, numerical methods were employed with machine computation to carry out the integration. The constants were obtained by curve-fitting the results to past data. Accurate population data are available[3] from 1900, but prior to this time accurate data were not recorded, and much uncertainty exists for early estimates.

For the period from 1650 to 1900, the estimates of Carr-Saunders[4] are generally considered to be the most reliable, but estimates for earlier periods differ by as much as 400 percent. Table I is a tabulation of estimated world population from zero A.D.; note that if the data of Carr-Saunders are accepted then the data of Durand[5] must be rejected since the two sets are incompatible. This situation is characteristic of early population estimates. Hence, for purposes of specializing Eq. (9), we have used selected data[4-8] as shown in Table II. Using these data, the following values of the constants in Eq. (9) were found to give an excellent data fit:

$$a = 5.0 \times 10^{-12} \qquad A = 0.10 \qquad k = 1.0$$

$$M = 50 \times 10^9$$

These results are plotted in Fig. 1, where the upper curves compare the solutions of Eqs. (6) and (9), and the lower curves compare the fertility rates given by Eqs. (5) and (8). Note that the data points are also plotted.

A sensitivity analysis of Eq. (9) was recently made[9] in order to determine the effect of variations in the parameters A, a, k, and M. Changes in A and a produced only a lateral shift in time, but a 1 percent variation in k produced a 20 percent variation in the upper bound M. Hence, k must be carefully determined, and an accurate prediction of M, as expected, depends upon the accuracy of existing data.

Comments on population growth. It is clear from Fig. 1 that if human population growth is not limited by effective artificial means, the upper bound will be reached in a relatively short time. The implications are profound since it is evident that environmental resistance will soon become the dominant mechanism limiting growth. The deviation between the coalition law and the modified coalition law will probably not be detectable until after 1980, and thus the credibility of the predictions made here will not be established until then. The precise value of M is open to question since Eq. (9) is sensitive to k. However, if k varies much beyond ±1 percent, an accurate fit of the data is not possible. Consequently, the upper bound likely will lie somewhere between 40 and 60 billion—a massive population in either case.

The most obvious conclusion is that world population continues to rise despite the considerable efforts to institute birth control methods during the last decade.[10] Further, note that the effect of World War II, a major catastrophe, has been negligible.

It seems clear, then, that if future population growth is to fall significantly below the predicted growth shown in Fig. 1, it will require either an effective, massive population control program, or a catastrophe on a scale many times greater than that of World War II.

Assuming that the population will grow "peacefully" along the predicted curve, it is natural to speculate on the credibility of an upper population bound of about 50 billion. It has been estimated[11,12] that the maximum possible population will be about 34 billion. This figure is based on an analysis of available arable land, temperature and water limitations, and the assumption that the future of life would remain equivalent to that in an industrialized state. This last assumption implies that the world could support more than 34 billion, but only at a reduced sub-

I. Estimates of population vs. time (millions)

Date, A.D.	1	2	3	4	5
0	300			<200	100
200	325				
400	340			220	
600	355				
800	390			240	
1000	430				200
1200	460			300	
1400	550				
1600	650			900	
1650		545			460
1700					
1750	791	728		694	
1800	978	906			
1850	1262	1171		1091	
1900	1650	1608		1550	
1920	1860		1834		
1930	2069		2070		
1940	2295		2295		
1950	2515		2517	2545	
1960	2998		3005		

Sources:
1. Durand (Ref. 5).
2. Carr-Saunders (Ref. 4).
3. Demographic Yearbook (Ref. 6).
4. "World Population and Resources" (Ref. 7).
5. Mills (Ref. 8).

II. Selected population data for curve fitting (millions)

Date, A.D.	Data	Table I Source	Reference
0	100	5	8
200			
400			
600			
800			
1000	200	5	8
1200			
1400			
1600			
1650	545	2	4
1700			
1750	728	2	4
1800	906	2	4
1850	1171	2	4
1900	1608	2	4
1920	1834	3	6
1930	2070	3	6
1940	2295	3	6
1950	2517	3	6
1960	3005	3	6

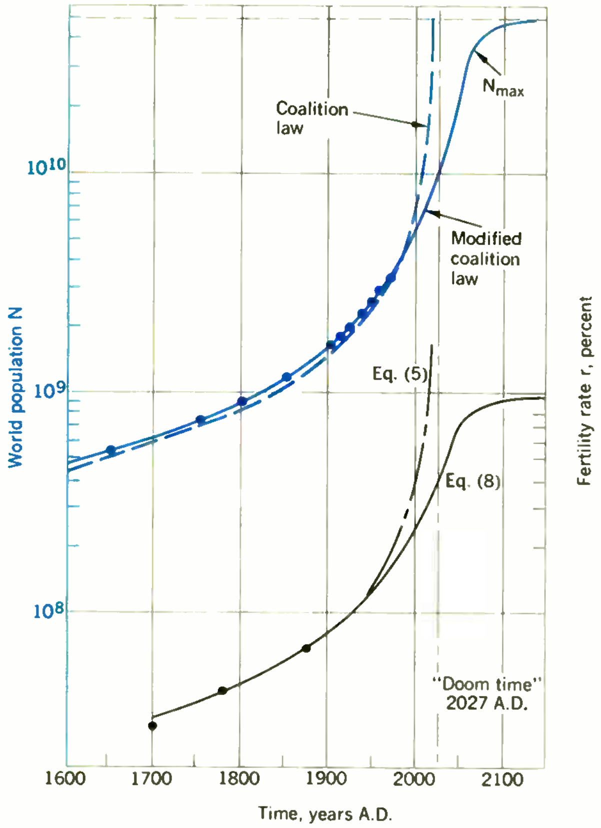


FIGURE 1. World population since 1600 A.D.

sistence level. Hence, the 50 billion prediction is not unrealistic, since the present population distribution (Fig. 2) indicates that about half of the world's population already exists at a low subsistence level and is increasing at the greatest rate. Further, the present distribution is expected to continue so that by 2000 A.D. this portion of the world's population will exceed 75 percent.[13]

If we accept the predicted growth in Fig. 1 as reasonably correct, then some rather profound inferences can be drawn. First, the time interval over which the growth occurs is relatively short. As shown, only about 100 years is required to reach a 40 billion population, which will require about ten times the existing facilities just to maintain the present quality of life. Although such growth may be possible in the already industrialized countries, it will be considerably more difficult on a worldwide scale. As needs increase, availability of resources will decrease, and the process of converting these resources, in turn, adversely will affect the productivity of the natural environment.

Second, the implication is that environmental resistance will become the dominant mechanism governing population growth. When this will occur is open to speculation, but a rough estimate can be made by noting the time at which the maximum growth rate N_{max} occurs. This is indicated in Fig. 1 at the year 2060—90 years from now, when the population reaches 38 billion. By this time the distinction between quantity of life and quality of life will become very clear.

Third, the only effective way to maximize quality of life is to stabilize the population in such a way that low birth rates and low death rates are achieved. Powerful arguments[14] have been made, however, to the effect that stabilization within this framework over the long run may be impossible, and that population will ultimately be controlled by high death rates. But this need not be the fate of mankind.

Although the coalition phenomenon is based on the precept that the clever population will continue to grow and industrialize, the outcome of the gigantic game with nature will be determined largely by man's awareness and understanding of the logistics concept. Some authors[15] claim that the effects of environmental resistance are already evident, and in order to stimulate thought regarding the relationship between technology and the ultimate quality of life, we will develop a few examples to illustrate the meaning of the parenthetical term $(1 - N/M)$ in Eq. (9). The following sections should provide some insight into the problems of maintaining a massive population through the process of industrialization.

Energy requirements

Perhaps the best index of quality of life is the energy consumption per capita. Even though the populace of North America uses about 30 percent of world energy supplies, it is meaningful to examine world energy trends since the energy needs of undeveloped countries will grow in the same manner as that of North America as these countries become industrialized.

World per-capita energy consumption is plotted in Fig. 3 (curve *A*); also shown is the total consumption per year (curve *B*) in terms of the convenient energy unit Q ($1\ Q = 10^{18}$ Btu). For insight into the magnitude of this unit, note that the total energy consumption in 1966 was 0.15 Q. As a comparison of destructive force, the energy released by a 1-megaton nuclear bomb is about 4×10^{-6} Q, or 4 μQ. The consumption-per-capita curve becomes remarkably linear beyond 1955, considered to be the result of the increasing industrialization of the underdeveloped countries. This can be demonstrated by an examination of the published data[16] summarized in Table III. These data serve to enforce the assumption that the per-capita consumption curve of Fig. 3 will remain linear over the near future (dashed line). Although long-range predictions based on such limited data may be questionable, Table III does give evidence that the per-capita energy consumption increase is presently greatest for those countries that have yet to undergo large-scale industrialization.

With the assumption of linearity for the future per-capita energy usage, we can use the expected-population-growth curve in Fig. 1 to construct the expected-energy-consumption-per-year curve (A) of Fig. 4; integration of this curve yields the total cumulative energy requirement (curve B). Figure 4 clearly illustrates the fact that world energy requirements will increase rapidly beyond the year 2000, if the population grows as predicted.

Accurate estimates of available fuels are difficult to obtain since the economics of recovery must also be considered. In 1952, Putnam[17] estimated that about 38 Q of energy is stored in recoverable fossil fuels (coal, oil, natural gas, and wood); however, Edlund and Beekman[18] recently estimated that only 14 Q of economically recoverable fossil fuels is available. Other estimates as high as 110 Q have been made. Even though there is a wide variation in the estimates, the magnitudes are not significantly different relative to world energy requirements

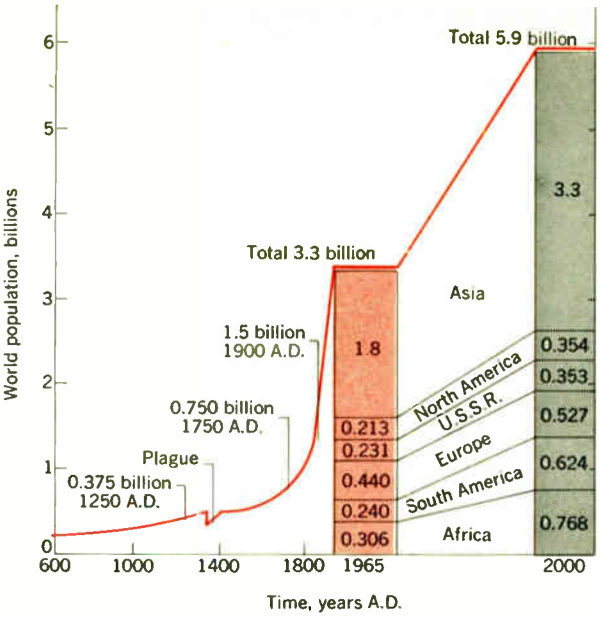


FIGURE 2. Expected world population distribution.[13]

shown in Fig. 4. Hence, the important conclusion is that energy derived from fossil fuels will not be easily obtainable in times as near as 50 years from now if consumption continues at the present rate. In addition, it is already being recognized that the continued use of fossil fuels will create the undesirable side effects of pollution and general environmental deterioration.

It is clear, then, that other energy sources must soon be developed for large-scale use. Hydroelectric devices provide only a small percentage of energy, and earth-bound solar-energy conversion devices require large collection areas but efficient methods have yet to be discovered. Consequently, it appears that nuclear energy remains the one source capable of filling future needs.

Uranium resources are more difficult to estimate since recovery is a strong function of cost. Edlund and Beekman[18] have provided a summary of existing estimates that is described in Table IV.

The data of Table IV are based on exploration limited by the needs of the U.S. Atomic Energy Commission during the 1950s and are, therefore, conservative estimates since further exploration undoubtably will reveal additional quantities. Furthermore, they are based on only U.S. reserves, which alone are sufficient to meet world energy requirements up to at least the year 2100. The imminent development of fast breeder reactors, and the ultimate development of controlled fusion reactions, will insure unlimited energy supplies. Thus, it is concluded that meeting world energy requirements is entirely possible.

This optimistic picture is clouded, however, when we speculate on the effects of releasing such a vast quantity of energy over such a relatively short period of time. The growth of energy consumption implies increasing industrialization for production of material goods and services, which in turn results in the ultimate consumption of nonrenewable resources. The attendant problems of resource depletion, waste, and pollution are already evident in the U.S. and are typical of a highly industrialized nation. On a future worldwide scale, these problems defy description.

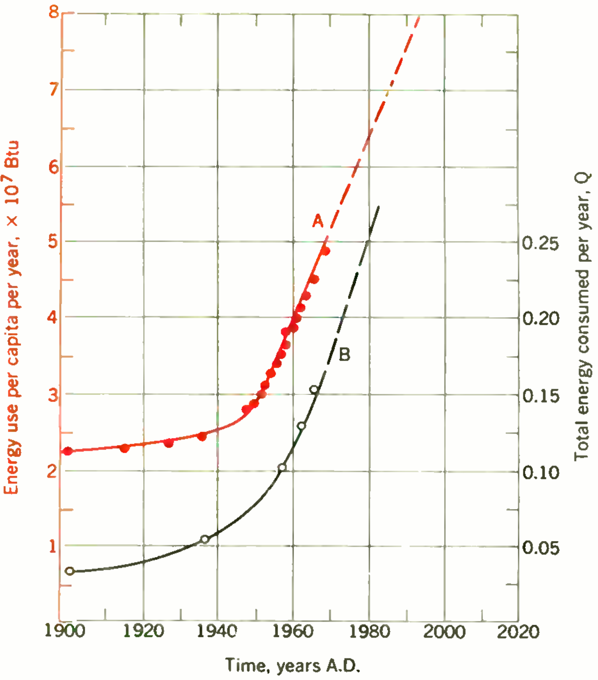


FIGURE 3. World energy consumption since 1960.[16] **Curve A measures the energy use per capita per year; curve B, the total energy consumed per year.**

It is clear, however, that as energy needs grow and are met, these problems will become increasingly important and manifest themselves as a form of environmental resistance. Waste and pollution are obvious examples and, for our present purposes, we shall discuss them briefly.

Pollution—some effects of energy consumption

The general problem of pollution is complex and not yet well understood. Air and water pollution by solid and gaseous wastes is currently under study and receiving much attention. It has become evident that the major source of air pollution in the United States results from the combustion of fossil fuels, particularly in the internal combustion engine. Elimination of harmful products of combustion can be achieved technically, but action will not be forthcoming until public pressure becomes great enough and/or the costs and necessary legislative actions are generally accepted. Hence, air pollution is considered here to be a solvable short-range problem, and will not be discussed further.

Regardless of the actions taken to eliminate harmful pollutants, the combustion of fossil fuels will continue to increase the atmospheric concentration of carbon dioxide, which will cause a continual increase in average temperature. This so-called "greenhouse effect" has recently received wide publicity, and is considered by some writers to be of sufficient importance to justify a general decrease in the use of fossil fuels. Since no other fuel has yet been proposed as a practical replacement for use in mobile systems, it is necessary to evaluate the importance of carbon dioxide production as a basic long-range problem, if only to validate or dispel the fears of those who advocate

III. Per-capita energy consumption (kilograms of hard-coal equivalent*)

Region	1958	1966	% Increase
World	1287	1648	128
Africa	250	289	115
North America	7422	9436	127
Other Americas	1274	1574	124
West Asia	318	539	170
East and South Asia	202	339	168
Western Europe	2388	3131	131
Oceania	2744	3747	137
Mainland China, U.S.S.R., East Europe, North Vietnam, North Korea, Mongolia	1106	1510	137

* 1 kg = 27 300 Btu.

the restricted use of fossil fuels.

The thermal energy exchange in the biosphere is strongly dependent upon the concentration of the minor gaseous constituents. Nitrogen, oxygen, and the rare gases have no significant effect, but the water vapor and carbon dioxide in the atmosphere provide the critical control on the radiant energy exchange between the earth, sun, and outer space to maintain the necessary temperature limits for life support. The water vapor content varies widely over the surface of the earth, but the carbon dioxide is well mixed throughout the atmosphere, so that changes in concentration have a worldwide effect.

The greenhouse effect arises from the fact that the fundamental absorption band of the CO_2 molecule lies in the infrared at a wavelength of 14 micrometers. As a result, the CO_2 in the atmosphere acts as an effective shield against long-wave thermal radiation back to outer space, but allows the shorter-wave solar radiation to enter freely. An increase in the CO_2 content, then, produces an increase in the average surface temperature of the earth. Gates[19] discusses this fully, and the reader is referred to his work for additional detail.

The increase in carbon dioxide content was first evaluated by Callender,[20] who constructed the curve drawn in Fig. 5, which shows a 13 percent increase since the industrial revolution began. Two additional plots (shown by crosses) have been added, and were derived from calculations based on the amount of fossil fuels burned during those years. In 1959, Plass[21] calculated that the increase from the years 1850 to 1950 should have increased the average temperature by about 1 °F. Since the average temperature increase recorded all over the world during this period was also about 1 °F, the carbon dioxide theory of climatic change has been considered valid. Many articles have since been written that appeal to this theory to warn against the long-range effects on the ice-age cycle. Gates,[19] however, points out that others have examined the greenhouse theory and generally concluded that order of magnitude changes in CO_2 content would be required to affect climate significantly. Specifically, in 1960 Kaplan[22] calculated that 10 percent variations would cause only a 0.45°F change in average temperature. It was concluded that localized effects of water vapor would dominate and would suppress changes attributable to carbon dioxide changes, and that the carbon dioxide hypothesis should not be considered the primary reason for major climatic changes. Nevertheless, the hypothesis is appealing and is not completely disproved. Therefore, we will use it here to evaluate the upper limits on carbon dioxide production through continued use of fossil fuels.

IV. United States uranium resources (thousands of tons*)

U_3O_8 price range, dollars per ton	\$5–10	\$10–15	\$15–30	\$30–50	\$50–100	\$100–500
Reasonably assured	190	150	170	5000	6000	500 000
Possible additional	325	200	440	3000	9000	2 000 000
Total	515	350	610	8000	15000	2 500 000
Cumulative energy content in Q†	26	43	74	475	1200	125 000

* 1 ton = 2000 lbs = 907. 18 kg.
† 1Q = 10^{18} Btu.

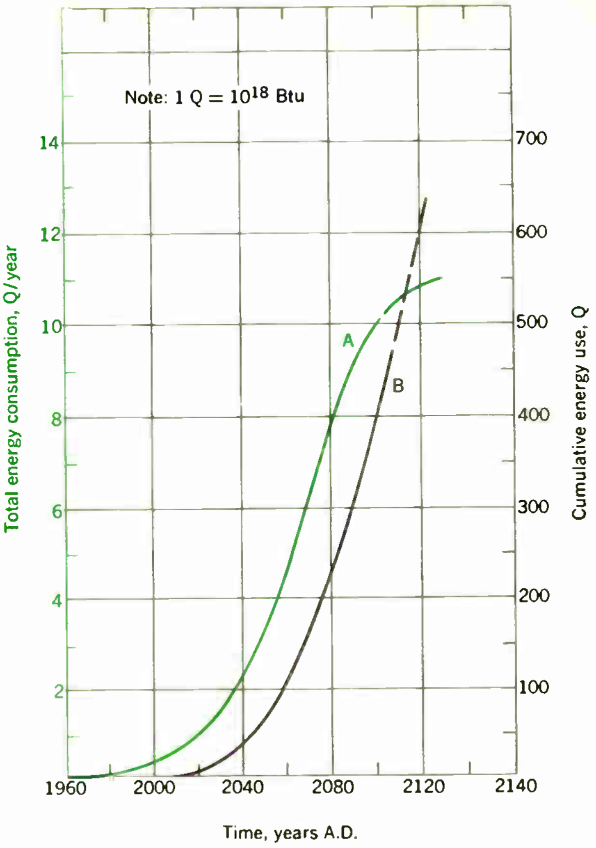


FIGURE 4. World energy needs since 1960. Curve A measures total energy consumption, and curve B indicates the cumulative energy use.

It is possible to quantify the long-range effects somewhat by estimating the total amount of carbon dioxide that would be released by combustion of all anticipated fossil-fuel supplies. Complete combustion of one kilogram of fossil fuel, of any type, produces about 3 kg of CO_2. For conservatism, we shall use the highest reported estimates of fossil-fuel reserves[23] and assume that all fuels undergo complete combustion. The results of these calculations are given in Table V.

If the present consumption rate is maintained, it can be extrapolated from Fig. 3 that the total fossil energy supply of 110 Q will be depleted by about 2060. Upon depletion, the total CO_2 content in the atmosphere will be about 0.15 percent, which is considerably less than an order of magnitude increase over the present concentration of 0.03

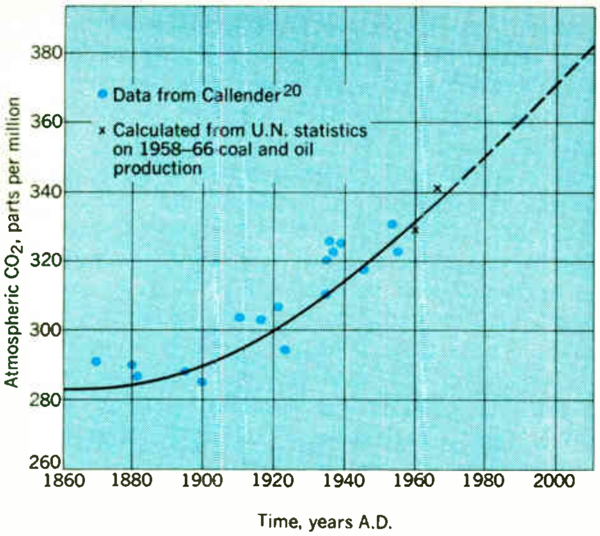


FIGURE 5. World carbon dioxide production from combustion of fossil fuels.

percent. Using Kaplan's value of 0.45°F/10% change and assuming linearity, the maximum possible temperature rise will be about 7.5°F. This is certainly a significant increase, but very likely never will be reached. The increased use of fossil raw materials for chemical synthesis of commodities, and, more important, the increasing use of nuclear fuels to replace fossil fuels, will slow the production of carbon dioxide considerably. The latter is demonstrated in Fig. 6, which illustrates future effects of nuclear energy on atmospheric pollutants. Further, it has been speculated[24] that an increase in carbon dioxide will stimulate plant growth, which will return greater quantities of oxygen. It is concluded that the greenhouse effect by itself is not sufficient justification to call for a drastic reduction in the use of fossil fuels.

Nevertheless, many current articles warn against the continued use of fossil fuels and the resultant long-range effects. For example, Tilson[25] estimated that the earth's temperature might rise by 3.6°F by the end of this century. It was not made clear, however, how this result was obtained, but he did speculate that much of the arctic ice cover might disappear, permanently flooding the coastal regions and converting the prime agricultural land into desert.

Another interesting point claims that pollution particles in the atmosphere may be creating a cooling trend by reducing the amount of solar energy reaching the earth, and that these two effects may tend to cancel each other. This is supported somewhat by reports that the average temperature has been dropping since 1950. Although the effects of atmospheric turbidity are open to speculation at present, the basic point is that these trends illustrate that much uncertainty exists regarding our understanding of the relationships between the activities of man and his environment.

Human activity is approaching the level at which environmental effects are produced on a global scale and are no longer localized. It is very timely and relevant to initiate extensive studies of these effects in order to develop criterions for regulating and coordinating the conversion and use of energy. Detailed analyses should be performed to determine the effects of future uses of fuels, the types, conversion processes, rates of consumption, distribution methods, and undesirable by-products in the form of pollutants and waste. Such a large-scale energy model would provide the necessary information for controlling and optimizing the long-range development of energy usage to provide maximum benefits by minimizing adverse effects.

For example, the results may show that widespread use of nuclear energy must be accomplished sooner than planned. Even though the use of nuclear fuels will reduce pollutants, other problems will arise that must be evaluated in the same manner. Problems of radionuclide production, radioactive waste disposal, and operational safety have all achieved notoriety largely through public misinformation. Although these problems are serious, they are not totally unsolvable, and are currently under study.[26] Nevertheless, we have reached the point where we must carefully distinguish between energy needs and energy demands or accept the fact that continued growth will require compromising environmental quality with energy affluence.

Fundamental to any energy conversion system, however, is the problem of rejected energy, which is inescapable by virtue of the second law of thermodynamics. As energy demands grow, the disposition of rejected energy, i.e., thermal pollution, will become an increasingly important problem. To illustrate this, consider the situation in the United States, which is probably typical of any highly industrialized country. At present, industry uses about 50 percent of the water consumed in the U.S., with 90 percent of this amount used for cooling purposes. The electric power industry uses about 70 percent of the total industrial cooling water, or about 19 billion m^3 per year. It is estimated that by the year 2000, the U.S. power industry will use about 38 billion m^3 per year. This is equivalent to somewhere between one fifth and one third of the annual fresh-water runoff.[27, 28]

At present, U.S. energy consumption is about one trillion kWh/year. If we assume an efficiency of 40 percent and further assume that all waste energy is removed by the cooling water, a simple energy balance reveals that the average temperature rise is about 12°F/year. In the year 2000, the energy consumption is expected to be about nine trillion kWh,[29] which results in an average increase of 55°F/year. The rate at which this heated water remixes with the cold source depends upon local conditions, which vary widely; hence these gross estimates need not be taken literally, serving only to illustrate trends. Already there is concern over localized heating of waterways, but if the trends continue, the problems will become more severe.

Unless new systems for energy conversion are implemented, the cumulative effects of thermal pollution may have a profound effect on aquatic life.[30] Solutions to these problems are already being conceived. Proposals have been made to base large reactors on artificial islands in the oceans, with high-voltage transmission to the land masses for energy distribution. In this manner, the flow of ocean cooling water can be maximized to facilitate mixing. Also, basing reactors in the colder regions of the world will allow the possible use of the waste energy for beneficial effects. Currently, the use of cooling towers is becoming widespread. These have special problems such as the introduction of large quantities of water vapor, causing fogging or excess rainfall, or are very expensive if

V. Estimation of CO_2 produced from total combustion of world fossil-fuel reserves

Fuel	Reserves	Energy Content, Q	CO_2, tons	CO_2 Concentration, ppm
Coal	24×10^{17} tonnes*	66	8.0×10^{12}	880
Crude oil	40×10^{11} barrels	24	2.0×10^{12}	220
Natural gas	62×10^{13} m^3	20	1.3×10^{12}	140
Totals		110		1240

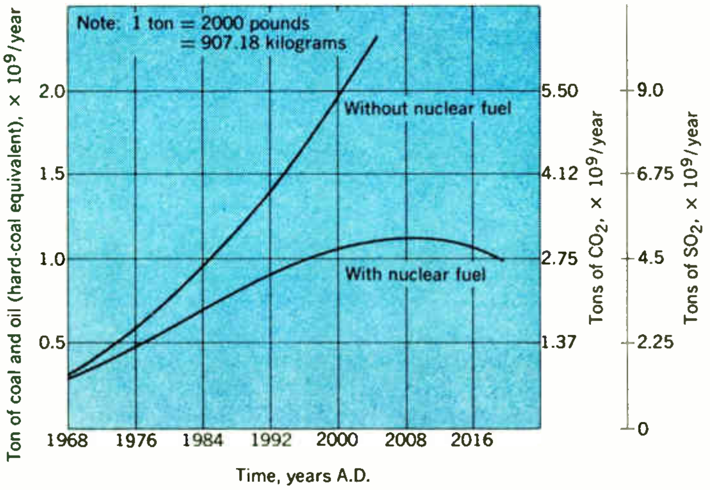
* 1 tonne = 1000 kg.

constructed on the principle of the automobile radiator. All of these schemes pose special problems and are, therefore, not panaceas.

The only effective long-range solution is to strive for more efficient operation of existing concepts as a stopgap measure until entirely new methods of energy conversion can be achieved. In the meantime, the deposition of waste energy is continuing at a rate that may profoundly affect the environment, and that will be manifested as an undesirable form of environmental resistance to life support. For this reason, the development of controlled nuclear fusion coupled with direct conversion of thermal to electric energy is of utmost importance. Reference to Fig. 1 shows that this program has only about 50 years to produce results in the form of large-scale, practical installations.

Although the production and conversion of energy is critical, the use of this energy is equally important. Increasing energy consumption implies increasing industrialization and the use or conversion of nonrenewable resources into functional products and services. Thus, the use, or misuse, of energy can be considered as a form of environmental resistance. To illustrate this, we can define an additional index of the quality of life in an industrialized society as the per-capita production of garbage. Figure 7 shows the history of refuse production in the U.S. These curves by themselves are not particularly enlightening; however, if we use these data to construct the plot in Fig. 8, which shows the per-capita refuse production per day as a function of the per-capita energy consumption per year, the result is startling. Even though the per-capita energy use for the U.S. is about five times the world average, Figs. 7 and 8 show that the efficiency of use is continually decreasing. This raises questions regarding the meaning of quality of life since both Figs. 7 and 8 indicate that there must be a point of diminishing returns if energy usage continues to result in increasing quantities of thermal and solid wastes. It is left to the reader's imagination to extrapolate the performance of one highly industrialized country to that of a future industrialized world. This exercise should leave one with a graphic understanding of the physical significance of the parenthetical term $(1 - N/M)$ in Eq. (9), representing the environmental resistance factor.

FIGURE 6. Projected CO_2 and SO_2 production by the U.S. power industry. (Source: M. Shaw, director, Div. of Reactor Development and Technology, AEC, testimony before 91st Congress, first session, Oct. 1969.[26])



The basic point is that the concept of waste disposal must be replaced with the concept of waste conversion. This will not come about without cost since energy will be required, and therefore will not always be the most convenient, or economic, path to follow. In order to prolong the availability of resources, the fundamental approach to engineering design must be altered to include environmental parameters along with the usual design criterions. Man-made systems, mechanical or otherwise, must be made to operate economically without resorting to the expediency of eliminating unwanted by-products by "throwing them over the back fence." Complex ecological systems, such as forests, have survived milleniums only because waste is minimized. Nature provides a closed system in which all by-products of each element are used by other elements. Hence, man-made systems must somehow be closed in the same way. This will be no simple task. In addition to the technical difficulties, there will be the dilemma of balancing short-range gains against long-range losses, since the latter are always ill-defined and seem less important at the time of consideration.

As population grows, it will become increasingly important to consider the environment as part of any system if the quality of life is to be continually improved through industrialization. The more complex societies become, the greater will be the interaction between man and the environment that provides his life-support capability. The technical challenges will be greater than ever, but will be met only by choice. This will require a general awareness of conditions and a change in the basic attitudes of everyone, and implies that strict resource management and environmental conservation must be accepted as a fundamental national, and hopefully international, purpose.

Food supplies

The most direct form of environmental resistance is the shortage of food. In order to provide some perspective on available food supplies relative to an expanding population, we will follow the reasoning used by Watt[31] to estimate food capacity of the earth. Human life support depends upon the conversion of solar energy to chemical energy. Gates[32] estimates the average available solar energy to be about 1.2×10^{10} kilocalories/hectare/year, where 1 hectare = 10^4 square meters. The total available arable land is about 4.6×10^9 hectares, which includes all lands under cultivation as well as lands that could be cultivated with additional effort. For an average human of 70 kg weight, basal metabolism is about 1700 kcal/day. Currently, the Asian mean per-capita intake is 2100 kcal/day. Hence, a generous allowance is about 3000 kcal/day, or about 10^6 kcal/man/year. With this information and the data provided by Kleiber,[33] Table VI can be constructed to give some insight into the food capacity of the earth.

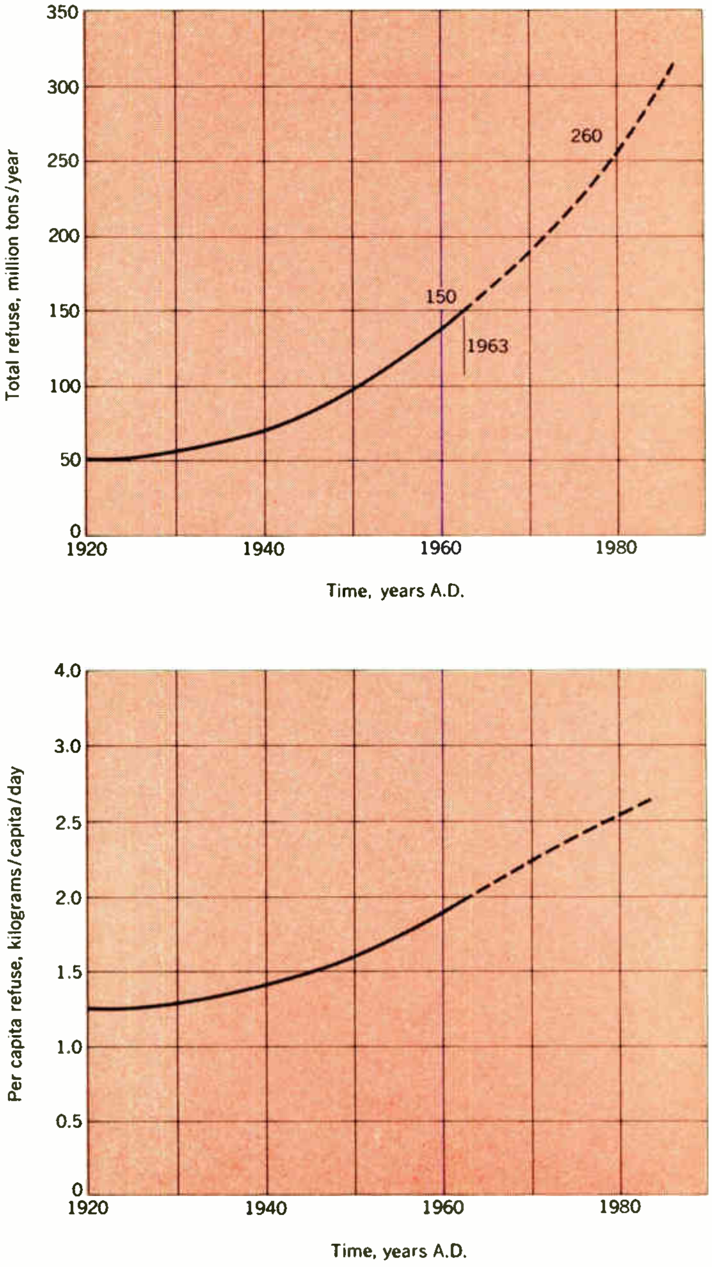
These data give a rough estimate of the upper limits on population, but the results are impractical since man requires a balanced diet consisting of many types of foods. Studies with such detail have been made[11,12] that show that 2250 m^2 are required for support at a 3000-kcal/day/man level. Based on approximately two crops per year, the equivalent available land area is about 7.7 by 10^9 hectares. Hence, the maximum population level is about 34 billion if existing agricultural methods are employed. The most significant feature of Table VI is that algae provide by far the most efficient energy-conversion process. This food source has yet to be exploited. Technically, it might be possible to double world food supplies if 50 million acres of tropical land were devoted to algae culture.[34] This, however, requires large areas of level land and large investments, and insufficient research has been carried out; thus, conventional land crops will remain the main food source for some time to come.

Overall trends in world food production are shown in Fig. 9, which illustrates that the use of marine food is low and might be expanded to meet future needs. The importance of this is demonstrated in Fig. 10, which indicates that per-capita food production has remained almost constant since 1962 despite the fact that much of the world's population continues to exist on as little as 2100 kcal/day. One obvious solution is to increase the seafood catch. The present catch is about 60×10^6 tonnes per year, which, at a level of 10^6 kcal/man/year, provides support for only 60 million people per year since a kilogram of seafood produces about 1000 kcal. Since the population will be about 6 billion in 30 years, the seafood catch would have to be increased 100 times just to feed about 10 percent of the population. It is doubtful that such significant increases can be achieved; hence, it will become increasingly important to develop methods to harvest sea plants as well as sea animals in order to supplement land crops. As noted in Table VI, this is advantageous from an energy-conversion standpoint. The difficulty, however, is that much of the sea plant life is low-density algae (1 m^3 of seawater contains about 1 cm^3 of algae) and, so far, no effective techniques for efficient harvesting have been devised.

In addition, there exist the problems of converting the harvest into a palatable food, as well as developing adequate storage and distribution methods. It is significant that no large-scale research and development programs to develop sea farming and harvesting methods exist. The need for such an effort is illustrated by Fig. 11, which shows that the per-capita food prodution of underdeveloped countries is actually decreasing even though overall world food production is increasing.

Caloric intake, however, is only a part of maintaining a healthy diet. Proteins are vital for growth during the crucial childhood years and are necessary for continued tissue renewal. They consist of complex combinations of some 20 amino acids, of which ten are essential to man. Plants are the fundamental source of proteins, but most common food plants produce incomplete proteins lacking in some of the essential amino acids. Thus, a healthy diet should include generous portions of protein from animal origin, i.e., meat, eggs, and dairy products. Although opinion differs on the optimum ration of animal protein, it is generally agreed that the high-quality animal proteins not produced directly by plants are absolutely necessary. An examination of the data published by the Food and Agricultural Organization (FAO) of the United Nations reveals that most of the world's population receives less than 10 percent of its protein from animal origin, and that since the 1950s the amount has been slowly decreasing. This trend is expected to continue since animals require large land areas, are inefficient "protein factors," and are a luxury that only the wealthy countries can afford. This implies that seafood will become an increasingly important protein source as population grows, but, as previously noted, methods of sea farming and harvesting must be greatly improved in order to develop a major food source. Hence, existing research

FIGURE 7. Refuse production in the U.S. since 1920.



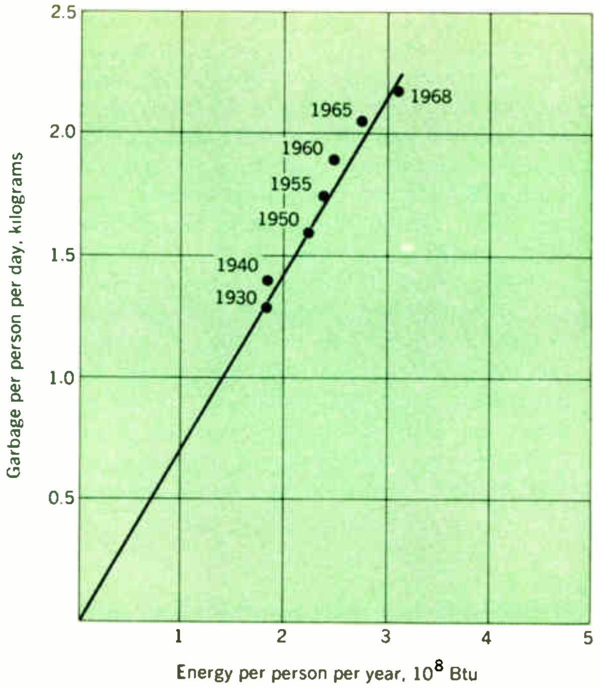


FIGURE 8. United States per-capita refuse production as a function of per-capita energy consumption.

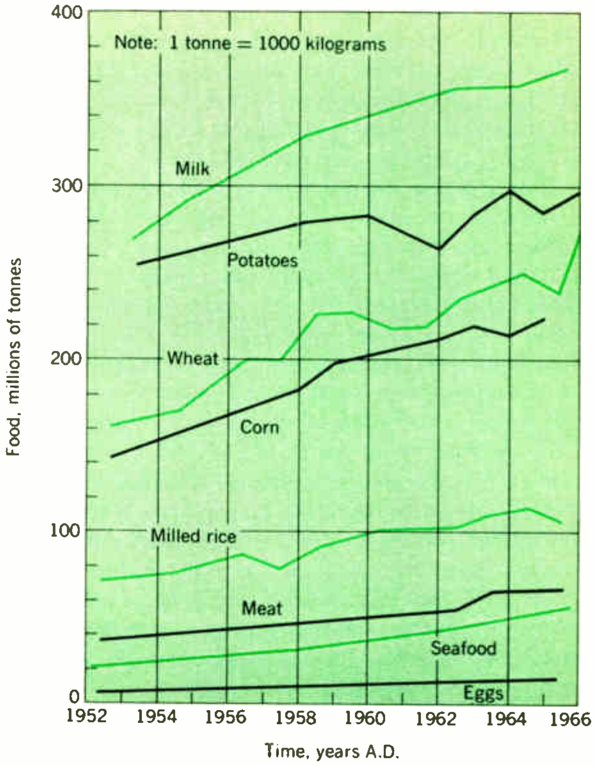


FIGURE 9. World production of major foods (except curve for seafood, data do not include mainland China).

and development programs to produce protein artificially must be accelerated. Since the population doubling time is about 30 years, time is critical. It appears, then, that grain will be the major food source, and, for the short range at least, wheat will continue to be the basic food.

Wheat is the only well-rounded bulk food that requires few changes in dietary habits, and is the only effective food that can be produced and distributed on a large scale. For economic reasons, the U.S. has been the only country capable of supplying wheat free of charge to undernourished countries, and will likely remain the major supplier. Paddock and Paddock[35] have made an extensive study of world food needs and supplies, and conclude that serious shortages will develop sometime between 1975 and 1985. Figure 12 summarizes their results. They are special cases since accurate data are not available, past politics may preclude U.S. food aid, and the U.S.S.R. is not usually considered an underdeveloped country in need of assistance. He points out that, even if fully cultivated, the U.S. will not have enough foodstuffs to satisfy future food needs of all hungry nations, and may soon be in the position of selectively providing food aid or rationing food surpluses.

VI. Food capacity of the earth

Crop	Efficiency of Conversion of Solar to Chemical Energy, percent	Approximate Area to Produce 10^6 kcal/yr to Feed One Man, km²	World Population Supportable by Terrestrial Resources Alone
Algae	12.5	13	9.1×10^{12}
Potatoes	0.1	1 550	7.5×10^{10}
Grain	0.05	3 100	3.8×10^{10}
Milk	0.04	3 900	3.0×10^{10}
Pork	0.02	10 400	1.2×10^{10}

Figure 11 illustrates that the population of the underdeveloped countries is increasing whereas food production is decreasing. Even though very recent agricultural developments are occurring, i.e., the green revolution to produce high-yield varieties of grain, time still remains the critical factor. Wharton[36] has recently provided a critical analysis of the promises of the green revolution. He states that even though the estimated acreage planted with the new high-yield varieties rose from 200 acres in 1964–1965 to 20 million acres in 1967–1968, it will be difficult to achieve the full potential offered by this new development, and that even if increased production is in fact obtained, a whole new set of second-generation problems must be solved if production is to be sustained and accelerated. The general conclusion is that even if a major effort were made today, there still may not be sufficient time to be effective, so that massive famine may only be delayed for a few more decades. There is optimism, but any increase in food production must be accompanied by effective population control; otherwise, the food gains will always be overtaken by food needs.

The final outcome is certainly open to speculation, but if the population growth continues as in Fig. 1, the effects of environmental resistance in the form of food shortages will be felt within the next two decades. It should be emphasized that the predicted upper bound of 50 billion people is based on the assumption that all necessary developments and full use of the earth's life-support capabilities can be achieved without major setbacks. In view of the foregoing discussion, this seems to be overoptimistic, and unless the population is controlled humanely, the all-important fertility rate, which is birth

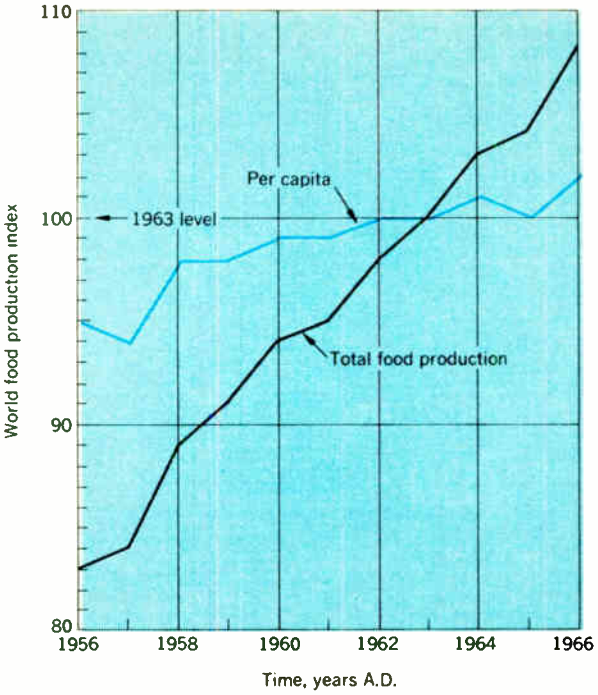


FIGURE 10. Total and per-capita world food production (excluding mainland China).

rate minus death rate, will be governed by high death rates.

Conclusions

The most obvious and important conclusion is that population growth is the major problem facing the world today. The population is approaching a level at which environmental resistance will soon become the dominant control mechanism unless some form of birth control is achieved on a worldwide scale. Time is the critical factor and, based on past performance of the human race, it is concluded that voluntary control will not be achieved in time to yield the luxury of choice between quality of life and quantity of life.

Hence, it is likely that in most parts of the world, the death rates will increase until fertility rates are zero or negative. The implications are that the developed nations will not remain unaffected, and will be required to play an even greater role in international affairs. Since the U.S. will likely play the major role, it is urgent that strong, well-defined national goals be established to remove the pressure of the major internal problems. Specifically, these should include an internal program for population control, resource management, and environmental conservation and restoration.

The specific technical developments required to achieve these goals center around the implementation of the following areas of research and development.

1. Development of techniques for the conversion of waste products into useful forms. The effort must include studies of methods of collection, storage, and redistribution. Most important, however, industrial activities must be revised to minimize or eliminate waste production and to facilitate the conversion of unavoidable wastes (e.g., new packaging methods must be developed).

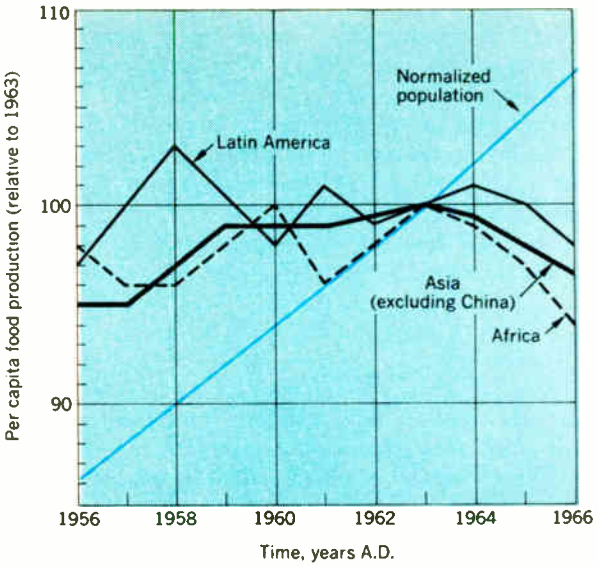
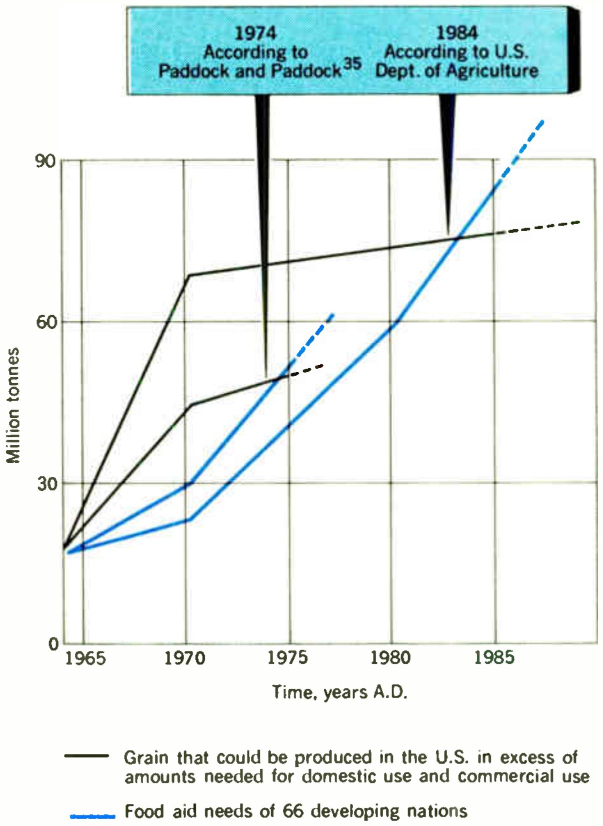


FIGURE 11. Per-capita food production by world area.

FIGURE 12. Comparison of food needs of 66 nations and United States food supplies.



2. Establishment of a central agency for control of the use of energy and natural resources with the overall purpose of providing a rational basis for national policies regarding growth and development.

3. Establishment of large-scale research and development programs for efficient harvesting of marine resources. Specifically, methods of harvesting sea plants and subsequent conversion into palatable foods, farming sea animals as land animals are farmed, and recovery

of inorganic resources must be developed.

4. Development, as soon as possible, of more efficient methods of energy conversion. Although nuclear reactor development is proceeding at a reasonable rate, accompanying programs to devise new methods for conversion of the thermal energy into electric energy are lagging. In addition, new fuels must be developed to replace fossil fuels for use in all forms of transportation systems.

5. Establishment of a national center for domestic studies that would provide the necessary coordination between disciplines to investigate the developing relationships between man and his fellows and man and his environment.

These programs are proposed as a means of coping with the needs of an expanding population, since it is assumed that effective population control will not be achieved over an extended period. At best, such programs, if instituted today with top priorities, could maintain the present quality of life. Continual improvement, however, will require population control on a worldwide scale regardless of the obstacles.

This article is a result of a special seminar recently developed at the Mechanical Engineering Department, University of California, Davis. The course was conceived by the authors as an experiment in engineering education for the purpose of involving engineering students in current and future social problems, and developing an awareness of the relationships between technology and quality of life.

The material presented here summarizes some of the topics discussed, and is partly a composite of some of the student projects. Hence this paper is a direct outgrowth of the stimulation and perspectives provided by T. Cataline, M. Conway, S. Jamison, H. Parry, C. Radcliffe, P. Rast, E. Ratzlaff, J. Riley, D. Vanderpol, G. Vanderpol, and J. Young, whose contributions and energetic participation are gratefully acknowledged.

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Arthur L. Austin obtained the B.S., M.S., and Dr.Eng. degrees from the University of California, Berkeley, in 1956, 1958, and 1963, respectively. While a graduate student, he lectured at the university and served as a consultant to the Lawrence Radiation Laboratory, Livermore. Upon graduation, he joined the laboratory full-time, and from 1965–1968 was associate division head of the Weapons Engineering Division. During 1968–1969, he was given leave to teach at the University of California, Davis, as an associate professor. The work reported in this article summarizes his research that year with Prof. J. W. Brewer to develop a new course in sociotechnological system analysis—societal engineering. Dr. Austin has since returned to the Lawrence Radiation Laboratory and is a senior staff member in charge of the mechanical engineering research program. He is currently working with Prof. Brewer on a monograph to be used as a text for new courses in societal engineering.

John W. Brewer (M) received the B.S. degree in engineering physics in 1960 and the M.S. and Ph.D. degrees in engineering science in 1962 and 1966, respectively, from the University of California, Berkeley. He has been an assistant professor of mechanical engineering at Davis since 1966, and has been active in developing methods for the probabilistic design of mechanical and structural components at the Nuclear Division of Aerojet General Corporation in Sacramento. Dr. Brewer is currently involved in research leading to the application of modern systems and control theory to environmental problems. He is a member of the ASME, Tau Beta Pi, and Sigma Xi.

Getting engineering students involved:

The Dartmouth/Tuskegee program

Better education for blacks is needed
if they are to handle their own problems
and thereby secure their fair share of a U.S. society.
An attack has begun against one education deficiency—
lack of an adequate number of well-trained black engineers

Fred K. Manasse **Dartmouth College**

In a pilot program of cooperative innovation in engineering education between Dartmouth College and Tuskegee Institute, several Dartmouth undergraduates, while resident at Tuskegee, taught and coached freshman engineers at the Institute in the fundamentals of engineering. The Dartmouth student–coaches also took courses in pursuit of their own degrees. Results of the program are presented and Tuskegee Institute student responses are assayed. Goals and future plans and their implementation are discussed.

A fundamental concept of engineering education is that an engineer's job is to apply his knowledge of the natural sciences (such as mathematics, physics, and chemistry) in order to solve social problems or satisfy a human need. Currently, many of these problems center on vexations caused, in part, by our technological achievements, including pollution, transportation snarls, overcrowding of cities, lack of electric-power reserves, and crisis in communications. Along with these problems (and their obvious need for solutions) are the more personal or individualized ones that involve the less affluent minorities and their quest for a fair share of our society. In the U.S., this problem is best evidenced by the rising militancy of nonwhites, especially blacks, whose restlessness is evinced by increased demands for better jobs and housing, and stress on improved education for their youth. Since many of society's problems are most acute for the less affluent, it is important that they have a voice and a hand in the solution of these problems.

Particularly acute is a shortage of adequately trained black engineers. Until very recently, the primary sources of black engineers were the few predominantly black technical colleges—of which Tuskegee Institute is representative. Not only must "white" colleges meet their obligations more fully by enrolling more representative student bodies (essentially, by adding black or Indian students), but the quality of education of black colleges must be raised. Also, engineering students must learn firsthand about racial problems and their relation to the larger problems of our society before they can hope to solve them.

In view of the current "student revolution" for relevance and involvement, the Dartmouth/Tuskegee program was conceived and organized after nine Dartmouth students visited the Tuskegee campus for a two-day conference. Students from Engineering Science 21,* an innovative Dartmouth engineering course, traveled to Tuskegee during the 1968–1969 Christmas vacation to discuss the course and present a report to a group of educators, administrators, and graduate students from predominantly black technical colleges. It was hoped that through this presentation a course similar to E.S. 21 could be started at Tuskegee's engineering school. The nine-man presentation was highly successful, and promoted increased communication between the two institutions.

During the spring of 1969, the initial planning of the exchange program began for the following fall term.

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* E.S. 21, Introduction to Engineering—"The student is introduced to engineering through his participation in a complete design project. The synthesis of many fields combining physical theory, mathematics, economics, management, and communication is required in the course project. Engineering principles of analysis, experimentation and design are applied to a realistic problem from initial concept to final recommendations. These conclusions are evaluated in terms of technical and economic feasibility plus social significance. Lectures and laboratory are directed toward the problem, with experiments designed by students as the need develops." [From Thayer School catalogue]

Several professors of the Thayer School of Engineering at Dartmouth College, but primarily the author, in cooperation with Prof. Z. W. Dybczak, dean of engineering at Tuskegee Institute, decided upon the general nature of the exchange program and solicited funds for its initiation. Four Dartmouth engineering majors were recruited for the project—three of whom had attended the original conference at Tuskegee.

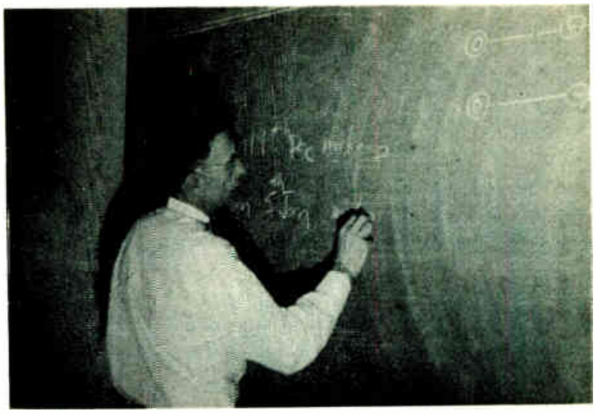
One of the four recruited students stayed at Dartmouth during the following summer in order to complete the plans and work out the logistics for the program. Various factors, including the manpower available at Tuskegee, limited funding, and the nature of the Tuskegee engineering curriculum, forced modifications of the original plans for the course. Instead of starting an E.S. 21 type of course at Tuskegee, a different approach was chosen. Although it would cover similar concepts, texts were to be added. The books chosen were *The Man-Made World*, Parts I and III—texts primarily designed for use by seniors in high schools, and authored by the Engineering Concepts Curriculum Project (ECCP). Laboratory equipment, including an analog computer, logic-circuit board, and various demonstration devices manufactured by the American Machine and Foundry Corporation, and around which the lab manual was written, was either borrowed from the ECCP office at Polytechnic Institute of Brooklyn (P.I.B.) or purchased.

The main emphasis of the Man-Made World (MMW) course, as developed by an NSF-financed committee headed by Prof. J. Truxal of P.I.B. and Dr. E. E. David, at the time of Bell Telephone Laboratories and now President Nixon's science advisor, was to develop engineering concepts as they apply in real-life situations for the nontechnical citizen. By discussion and laboratory experiment the student learns about such methods as modeling, simulation, criterions, decision-making, control, and computation. The concepts of stability, feedback, reliability, and queuing are covered specifically but in a generally qualitative way with some low-level overtones of quantitative measurement.

In August 1969, Prof. J. G. Tryon, the new head of the Department of Electrical Engineering (designated to take charge of the course at Tuskegee), the author, and the four Dartmouth students met with various educators and representatives from ECCP for a week-long workshop.* The primary purpose of the meeting was to formulate goals for the MMW course. Secondary purposes were to discuss various teaching methods that would be employed, the relevance of the material to be presented, and the advantages and limitations of the text used.

In retrospect, the workshop had merit, but was only partially successful. It was a very valuable experience in that it gave the Dartmouth students an opportunity to practice teaching; however, it inadequately served to prepare these same students in the skills required to make proper use of the equipment.

The goals in directing the MMW course were by their nature hard to define. This was the first time MMW was offered at Tuskegee; indeed, it was one of the first times for MMW to be taught at the university level. Also, neither Professor Tryon nor the Dartmouth students had any experience with the Tuskegee engineering major. The three goals finally decided upon were


PROF. TRYON of Dartmouth lectures at Tuskegee.

1. To develop thought patterns essential to the study of engineering in each student.
2. To arouse general interest in engineering.
3. To reteach poorly learned high-school material (back material) in an indirect manner.

These three goals provided guidelines around which the MMW course was taught, and formed criterions for determining its success.

The course at Tuskegee

The inclusion of MMW in Tuskegee's curriculum provided a basis for a Dartmouth "project type" of engineering education—that is, a tutorial colloquium wherein the engineering student gains an understanding, not only of science and technology, but also of social conditions. The goal of such a program is to train engineers to work within society and not apart from it.†

The MMW course taught in the fall of 1969 was decidedly experimental. Originally conceived as a course for high-school students, it and the texts were adapted to fit the needs of Tuskegee.

There were 64 students enrolled in the MMW course; all met at the beginning of the course week for a one-hour lecture. Then the class was broken into small (six- to eight-man) groups for afternoon lab meetings. The instructors constituted a six-man team (Professor Tryon, a Tuskegee graduate student, and four Dartmouth

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* B. Sachs, then an associate director from the ECCP office, kindly stayed the whole week and greatly assisted in the teaching of the course. T. Liao, an assistant director, also from ECCP, stayed one day and lectured on some of the computer aspects of the course. In addition to the students who were going to Tuskegee, several Dartmouth students who were to go to Jersey City (on a companion project) and a high-school teacher who would be involved in that program were participants in the workshop.

† The general statement of purpose of the Thayer School of Engineering is: "The entire undergraduate engineering sciences curriculum may be considered as a new form of liberal arts education polarized about the engineering sciences. It serves as a foundation education for the profession of engineering in the same way that conventional liberal arts education, centered about the social sciences and humanities, serve the law profession. Just as a social science–humanities centered education permits the adoption of many vocational fields so the engineering sciences based undergraduate education may, in the liberal arts tradition, give a student a level of intellectual preparation so that he may properly elect graduate study in law, business, economics, industrial administration, physics or mathematics, as well as engineering. In a rapidly changing technologically-based economy such as ours it is increasingly obvious that a liberal education is necessary for those aspiring to industrial and public leadership." [From Thayer School catalogue]

students); each instructor* taught two lab periods (six hours) per week.

The purpose of each week's lecture was to introduce new material and to prepare for following lab periods. The laboratory section (involving three fourths of the students' four contact hours) was by its nature the more important part of the course. Generally, the function of the lab was to explain and discuss in detail the material started in lecture, and to carry out experiments that gave the students the opportunity to work with the equipment.

MMW offered two benefits: First, it provided the freshman engineering student with a foundation for problem solving in many areas, which is certainly important if the student must place the role of the engineer in perspective; second, because the interaction between student and teacher was conducted in small groups (of six to eight men), the course provided personal attention, which allowed the instructor to evaluate the students' strong points and weaknesses more accurately. For experiments, lab groups were broken down further into three- to four-man subgroups, thereby maximizing use of the available equipment.

The flexibility of the MMW course also made it possible to cope with students' poor science background.

> "Often we devoted lectures, homework and lab periods to helping the students learn material not taught at all or poorly taught in high school."†

The students *were* the course, and they knew it. Because of this unique relationship, they did not really mind working four semester-hours for a two-credit-hour course. The fact that the instructor–coaches were always available for questions made the classroom environment conducive to learning.

The organization of the MMW course fulfilled the three course objectives originally proposed.

> "We were able to create student interest, through small-group interaction and interesting material, while setting the stage for instructing the students in basic engineering concepts. . .
>
> "One student expressed his feelings about Man-Made World by saying, 'It is the only lab where I can walk in at two o'clock smiling, and walk out at five o'clock the same way.' Another said, 'We need it next year. Tell the Dean we as young engineers are looking to him.'
>
> "Although not a formal part of the course, we gave supplemental lectures on the slide rule, graph reading, and maintained office hours for those students who needed help with assignments. The scope of material covered in the formal presentations was limited to conceptual and mathematical methods, but during office hours we tutored in such subjects as world civilization, English, and calculus. Perhaps the biggest contribution of the MMW was showing the students that the material in mathematics and physics is directly connected to engineering."

The MMW course provided an overview of what an engineer does. Its content often conflicted with the students' conception of an engineer as one capable of making logically correct decisions.

> "By building on the student's personal experiences, we were able to present two major (engineering) concepts: (1) decision-making, and (2) modeling.
>
> "We presented the student with a systematic approach to decision-making by developing the ideas of alternatives, criteria, and constraints." The first step was to have discussions on various topics requiring each group to make a decision. Topics such as "How can registration at Tuskegee be improved?" promoted interesting discussion by the students, while permitting the instructor to point out the formal structure of the decision-making process. Sufficient examples were given for the student to understand the process of making decisions.
>
> "Building on the idea of decision-making, we developed the idea of the model. However, the conceptualization of a model was difficult for the students; many equated the term model with a small reproduction. Our first procedure was to present the model as a way of gaining more information about a problem. Our method included homework assignments, lectures, and laboratory discussions.
>
> "Tuskegee, like most urban areas, has traffic jams; a question placed before students was to define the traffic problem, thereby leading to the development of a number of alternate solutions. Each group of five or six students postulated possible causes of the problem and then made traffic counts. From these counts they were able to express the real situations in terms of flow rates, rate of backup, and other parameters. Using their data, they were able to make some statements of possible problem solution: i.e., alternate routing or traffic light sequence."

TUSKEGEE STUDENTS work lab experiment as a group.

The analog computer was introduced as a modeling tool because it offers

1. Immediate feedback to the student.
2. Introduction of other engineering tools, such as oscilloscopes and meters.
3. Opportunity to solve problems without advanced mathematical techniques.

As part of their class work at Tuskegee, the Dartmouth coaches were enrolled in an education course and prepared a questionnaire about MMW that they distributed to their freshman groups.

The overall impression from the Tuskegee students' responses is that they not only enjoyed the course but

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* The Dartmouth students were called coaches rather than instructors in order to minimize the normally expected student–teacher role difficulty.

† This and subsequently quoted passages are taken from a report prepared by Dartmouth students who participated in the Man-Made World course.

learned from it. They liked the style and team approach as well as the material and are better prepared for their future engineering work because of it. Overall, then, the course, although experimental in nature, and necessarily loosely structured, seemed to go well.

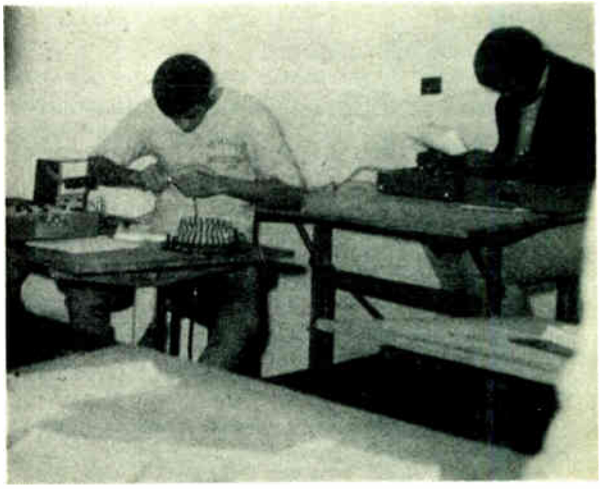
Dartmouth coaches as students at Tuskegee

The primary function of the Dartmouth/Tuskegee exchange program in its first year was the establishment of an introductory engineering course, the Man-Made World, based on an E.S. 21-equivalent introductory course at Dartmouth, and staffed by Dartmouth juniors. In addition to their roles as coaches, however, the Dartmouth men also held roles as students at Tuskegee.

> "The details that follow do not attempt to imply that our presence on campus had any great effect. Our concern over 'making waves' on the campus prevented our participation in activities that might have unpredictable effects."

The effects of interaction between the four Dartmouth students and the Tuskegee campus were primarily felt by the students, not the campus.

> "Dartmouth College required that we take three courses to receive full term credit. All of us did so, with one student taking four courses. We received no course credit for our work as instructors. In order to find challenging and interesting courses we discovered that we had to take senior and graduate-level courses. It is important to note that taking three or four courses at Tuskegee requires less work than taking three courses at Dartmouth*; this characteristic was helpful because it allowed increased concentration in the teaching of The Man-Made World.
>
> "In the classroom, our presence affected the [other] students and professors in several ways. We were told by friends that during our absence from class for a few days, the discussion in class became less inhibited; apparently our presence made our fellow students somewhat uncomfortable. In one case a professor asked us not to take his course. When he was finally persuaded otherwise, he asked us not to appear at several classes—his reason: the white student's presence upsets and slows discussion. In some cases, however, our presence stimulated discussion. Often we were called upon to give the 'white point of view' on a certain issue.
>
> "It is difficult to state whether we received differential treatment from our professors at Tuskegee; however, our uncertainty indicates that such prejudice was minimal, if it existed at all.†
>
> "In addition to our instructing and academic life, we participated in extracurricular activities. Each of us attended several lectures and informal discussions both on and off the Tuskegee campus. The dormitory advisors were very energetic in organizing activities such as these, and were concerned with including us in most of them. One of our group was repeatedly asked to be a 'student reactor' to speeches given by faculty members or members of the Tuskegee community.
>
> "Often extracurricular and academic activities were combined by a student. For instance, one of us wrote a paper on the school system of Tuskegee, Alabama—the state of desegregation there. This involved getting out into the community to hear people speak, and interviewing school officials and pupils. Papers on farm cooperatives in the South, and the state of industrial development in Tuskegee, Alabama, were also written.
>
> "Our social life at Tuskegee was minimal. During our short stay we found it very difficult to break into the black subculture. For the first few weeks we attempted to do so, by eating, rooming, and mingling apart from one another. As the term passed, we began to see more and more of each other as our failure to enter fully into the social life of the campus drove us together.‡
>
> "On campus the purely social forms of entertainment were movies, and occasional concerts. We took advantage of these events as often as possible. Frequently we drove 20 miles to Auburn University to socialize on that campus; to our surprise, their acceptance of us was minimal as well.
>
> "On weekends several of us would leave Tuskegee for the Gulf Coast, Selma, Alabama, Washington, D.C., New York City or elsewhere. This reflects the fact that we were not socially comfortable at Tuskegee, and therefore preferred to be elsewhere for our social activities.
>
> "Concluding our experiences, then, we say that although our academic, extracurricular, and social activities at Tuskegee are not included in the primary goals of the exchange program, they did form a large part of the experience. The benefits of our interaction with the campus in these areas accrued to ourselves, as opposed to the benefits of our instruction in the Man-Made World, which accrued chiefly to the Institute. Any individual on exchange to Tuskegee must be prepared to give a great deal to Tuskegee as an instructor, and gain a great deal in the other areas of his existence on campus."



AT TIMES, students experimented by themselves.

The impression that the Dartmouth students received as much as they gave is evidenced by a number of items. Their academic grades at Dartmouth since their return

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* This is true for a number of reasons. First, Dartmouth has three terms per year and students normally only take three courses per term whereas Tuskegee has two semesters per year and most students take five or six courses per semester. In addition, entering Dartmouth students are generally better prepared than Tuskegee students so that equivalent-level students do not necessarily study at corresponding levels.

† Of course, the presence of exchange students in the classroom is not a new experience to Tuskegee professors—the University of Michigan has an exchange program there.

‡ It is interesting to point out that one Dartmouth "intern" was black, yet his reactions and responses differed little from his white colleagues. However, his stay at Tuskegee was more socially rewarding since Tuskegee is coed whereas Dartmouth is not.

have improved somewhat over their previous scores. They are more mature and more capable of managing their time, resources, and social activities. They are more involved in extracurricular affairs and are active in black–white matters on campus. The rest of the Dartmouth faculty is impressed with their accomplishments on a personal and individual basis. In many ways the success of the program in future years rests on their shoulders and they are aware of it. They would like to continue an association with the program and have made numerous suggestions, the substance of which is contained in the recommendations for future plans. There is no question that their enthusiasm and dedication are responsible for the acceptance and continuation of the program.

Overall evaluation

How successful was the Man-Made World (that is, the Dartmouth/Tuskegee exchange program) from both the Tuskegee and Dartmouth points of view? The question is a vital one, for its answer bears on the future of the course and the program.

The measure of success in the course from the Tuskegee perspective can be evaluated by the measure of success achieved with the initial three goals (see page xx).

All goals were attained to varying degrees. Judging by performance on examinations and in laboratories, the men achieved a degree of proficiency with the problem–alternatives – model – criterions – constraint – optimization method of thinking. Members of the MMW staff and of the engineering-school administration feel that without this course the important engineering thought patterns might take additional years for a student to understand.

The MMW course apparently provides a glimpse of engineering that either entices the students onward, or, in a few cases, indicates that their interests lie elsewhere. Evidence to support this contention appears in responses on the questionnaire that each student filled out. It also was apparent when speaking with the students. The parallel of this course with real engineering problems, as opposed to the more theoretical nature of mathematics and physics, created a feeling in the students that it was preparing them more effectively for engineering; therefore, their interest in engineering increased.

The third goal, to reteach poorly learned back material, proved more difficult to attain. At first the staff underestimated the students' lack of education in certain areas, especially mathematics and English. Indeed, many students were taking remedial courses in a variety of disciplines. Attempts were made to improve the students' ability to communicate in close-interaction situations, to give the students a faith in themselves to make decisions, and to express themselves in a concise manner. A revised textbook or set of notes more attuned to the Tuskegee student would provide a better opportunity to teach the concepts of the MMW and achieve goal 3.

Dean Dybczak of the engineering school, his advisors and faculty, the students involved, the Dartmouth coaches, and the Dartmouth advisors to the program all feel that the course can be termed a success in its first year, based on fulfillment of the original three goals. It is further recognized that improvement is possible, and necessary, in a second-year program. All are confident that this can be accomplished with similar personnel and improved equipment and facilities.

From the Dartmouth point of view, the course achieved many of its goals. It brought together the faculties and students of two schools who have much to learn from each other. It prepared the foundation for more extensive cooperative efforts in student exchange, faculty interaction and exchange, and course expansion and revision. The Dartmouth students gained a great deal in terms of experiencing a culture and method of life far different than theirs. The very fact that they were three white faces among a black majority and felt the same undercurrent of hostility that their black colleagues at primarily white Dartmouth must feel was valuable as an experiment in tolerance and brotherhood. Our students became more appreciative of what they have and their improved performance on their return to Dartmouth attests to that.

Recommendations for the future

Although the experiment can be classed as successful and both schools and their students and faculties appear to agree on many major points, certain modifications and recommendations for the future are in order.

- Change time allotments to reorder the course emphasis. The freshmen at Tuskegee were taking the MMW course for two credits (one lecture and three lab hours) and a graphics course for one credit (three lab hours). This allowed inadequate time for both subjects and for the fall of 1970 it is planned to use the entire time for MMW—including graphics in the course so that a 3-credit-hour course will result (one lecture and six lab hours). The purpose is to provide more time and corresponding credit for material that appears to have been valuable in educating freshman engineering students.

- Incorporate Tuskegee students in the teaching–coaching team to make the entire process of education for the freshmen more cohesive. This expansion would include both underclassmen (sophomores) who have gone through the course, as well as possibly interested upperclassmen and graduate students. Not only would this create better communications, and therefore closer interaction and better instruction, but it would impose a continuity from one year to the next since some of the same people would be participants. We might point out that Tuskegee upperclassmen petitioned their dean and faculty to be permitted to participate: they claimed our students and their freshmen were "having too much fun." Since the intent all along was to involve primarily local students, this implementation of continuity merely puts into practice an initial goal of the program. It also relieves the Dartmouth contingent from having to spend additional coaching time because of the expanded schedule of planned class hours.

- Prepare new material in the form of notes to augment the text, *The Man-Made World*, which has been found to be somewhat inappropriate for engineering freshmen at a black technical college. Our Dartmouth students have done some of this rewriting and have been spending the summer working as a team to prepare suitable expansions and explanations of the text subjects. In addition there is a real need to provide text problems that better fit, and are more relevant to, the rural experience of most Tuskegee students rather than the urban view of the students for which the text was originally conceived.

- Incorporate time-sharing computer terminals and teach the Basic programming language. Hopefully, funds for connecting teletypewriters at Tuskegee to Dartmouth's time-sharing computer by telephone line will be made available to permit the freshmen to gain hands-on experience as well as access to the many computer programs developed at Dartmouth. This also will permit Tuskegee's other students and faculty to learn about the usefulness of the computer in education. Indeed it is hoped that the Institute will eventually serve as a time-sharing computer center for local schools and colleges just as Dartmouth now serves New England. There seems to be little doubt as to the value of the computer in the MMW course.*

- Follow the course with a Tuskegee version of the Dartmouth engineering course E.S. 21 (which started the entire cooperative effort and which was mentioned earlier). The logical extension of the conceptual content and training of MMW would be to *apply* it to a problem of local, regional, or national interest as is done in E.S. 21. The success of our workshop in 1968 at Tuskegee, the wide acclaim given the course at Dartmouth, and its numerous imitators at other institutions indicate that such a plan would likely succeed. The fact that Prof. Tryon had been involved as a visiting faculty member at Dartmouth with participation in E.S. 21 and is both willing and anxious to start such a course at Tuskegee are important reasons to consider this as a future objective. Our hope is to implement this advanced course during the spring term following the expanded version of MMW planned for the fall.

- Expand the program into a two-way exchange (to include Tuskegee students at Dartmouth) and extend it to include graduate-student and faculty interchange. Any effort that remains one-sided is doomed to eventual failure: participation must be cooperative to be really effective and of long standing. The plan has always been to have Tuskegee students "swap" with their Dartmouth counterparts—making for a simple "body-for-body" exchange. This would considerably ease administrative details such as housing, registration, and fees. It was not implemented the first year primarily because Tuskegee's students were somewhat skeptical of the entire project and because of the logistic difficulties they encountered. Chief among these is the two-semester–three-term difference between institutions and the increased cost of tuition Tuskegee students would face at Dartmouth. We believe that these problems can be worked out and, indeed, several Tuskegee students with whom our Dartmouth juniors had become friendly have expressed strong interest in attending Dartmouth. The nature of E.S. 21 is such that it would be extremely valuable for some students at Tuskegee to be exposed to it at Dartmouth before participating in its inception after their return. We are currently engaged in completing formal arrangements for these students on our campus.

The proposal involving an exchange of graduate students and faculty members already has been implemented, but only on a one-way basis: a permanent member of our faculty used to teach at Tuskegee and a student who is just completing the master's degree at Dartmouth was an undergraduate at the Institute. However, we would like to complete the loop and have some Dartmouth undergraduates go to Tuskegee for graduate work and have Dartmouth faculty spend some time at Tuskegee. Although I and other Dartmouth faculty have been there on several occasions, these stays have not been of long-standing duration. We most certainly intend to enlarge that exchange in the coming years and will seek funds to accomplish all these ends. The nature of E.S. 21 again will involve the participation of more members of both faculties to be, for example, participants on review panels, so that regular exchanges of personnel will be facilitated by the incorporation of that course at Tuskegee.

- Although not required of the specific program, we would also like to see other departments at both institutions begin to cooperate. The enrichment of both institutions by making their students and faculties aware of available differing academic courses, ideas about and approaches to education, new geography and political climates, and the obvious advantages for improved racial harmonies to be derived from a larger commitment are desirable goals. All Dartmouth students returned with new understanding and appreciation, and it is hoped that they, in turn, left similar "symptoms" at Tuskegee.

These recommendations have been stated in a rather general manner because the program will and should evolve on its own and generate its objectives, goals, and procedures in course. Nevertheless, it is hoped that some of these plans are at least tried since they would appear to generate better and more meaningful cooperation. Presuming its value, we would also like to see other colleges and universities follow our lead and develop their own imaginative approaches to cooperative engineering education. Certainly the key element in all these programs is that they are carried out on a student-to-student basis. We feel that only if this is kept as the primary goal can cooperative effort really stay socially and educationally meaningful over extended periods.

The Ford Foundation provided the funds for a nine-man group from Dartmouth to travel to Tuskegee and begin initial discussions relevant to the implementation of the E.S. 21-type course at the Institute. It also provided funds for the summer session. The Sloan Foundation provided the grant to help purchase equipment and provide the travel expenses for the actual MMW project. More than 100 sets of text, *The Man-Made World*, were donated by the McGraw-Hill Book Company.

Fred K. Manasse (M) is an associate professor of engineering at Dartmouth's Thayer School of Engineering, and is involved in electronic-device research and educational innovation. Previously, he had been with the Bell Telephone Laboratories (1956–1963) the Electrical Engineering Department of the City College of New York (1963–1965) and Princeton University (1965–1968). He split his working term with Bell to study theoretical physics at Princeton and received the Ph.D. degree in 1962. (He had previously earned the B.E.E. and the M.E.E. degrees from the City College of the City University of New York in 1956 and 1958.) At Bell, he worked in the Electronic Switching Systems Group and while there designed special-purpose digital filters. Also, as an assistant professor at Princeton, Dr. Manasse specialized in microwave-solid interactions. Dr. Manasse is a member of the American Physical Society, American Association for the Advancement of Science, Comité Gravitation et Relativité, New York Academy of Science, Sigma Xi, and the American Society for Engineering Education.

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* See the article on the Jersey City program in the forthcoming special June 1971 issue of the PROCEEDINGS OF THE IEEE.

Power, pollution, and the imperiled environment

II. East, Midwest, and West Coast: pollution-control plans of some major utilities; role of government in environmental matters; other proposed systems for reducing stack emissions

Utilities in the U.S. are very aware of the present public anxiety concerning the deteriorating environment. This concluding installment examines some of the specific programs being evolved in coping with this grave problem

Gordon D. Friedlander Senior Staff Writer

A number of the largest utility companies are embarking upon large-scale nuclear generating plant construction programs that may phase out up to 50 percent of their fossil-fuel stations by the end of the present decade. This move is being encouraged by the electrical suppliers, who, with the utilities and the AEC, are striving to convince a skeptical public that nuclear stations are completely safe and provide the best means for air-pollution abatement. Nevertheless, many fossil-fuel plants are still being planned and built, and more efficient methods of reducing stack gas emissions will have to be incorporated at these facilities if a general reduction in air-pollution levels is to be achieved while simultaneously meeting the accelerating demand for more electric energy. Government, too, has a role to play and a responsibility to fulfill in the public interest by enacting fair and practicable pollution-control legislation, and ensuring the enforcement of such statutes.

It is alleged in environmental studies by responsible groups that the United States, although it represents only 6 percent of the world's population, contributes almost 60 percent of the world's pollution. We are, without question, the most affluent and technologically oriented society inhabiting this planet and our demands for goods and services are, by far, the greatest. It is not surprising, therefore, that our demand for and production of electric energy exceed that of any other nation.

The contribution by the power industry in terms of percentages of the total air pollution from all other sources, for example, depends upon a number of variable factors. These include

1. Type and grade of fossil fuel employed.
2. Proximity of plant sites to heavily populated areas.
3. General topography and geography of area.
4. Prevailing climate and meteorological conditions.
5. Proximity and number of other industries in relation to power plant sites.
6. Concentration of power plants in any given urban area or city district.

According to industry estimates, the percentage of air pollutants from power plants in the U.S. varies from a low of one percent to a high of 15 percent of all air pollutants. Estimates from groups outside of the power industry, however, rate the contributions in higher percentages.

Two sides of the same coin

As we noted in Part I of this series last month, one can find diametrically opposed viewpoints on the issues of nuclear generation, for instance, from prominent practitioners and experts in the field. One can also find predictions and projections on the future of our environment from equally eminent authorities that range from abject pessimism to unwarranted optimism. We also have protectionist interests active in the dialogue. Thus it is understandable that the power industry is not eager to overstate the problems of pollution for fear of fanning the fires of public alarm. Similarly, the electrical and mechanical suppliers, whose interests lie in selling heavy equipment to the power industry, will direct their promotional emphasis toward the safety aspects and nonpolluting qualities of their products.

On the opposite side of the coin is the general public, whose rights as consumers, as well as those of the power industry as producers, should be protected by government as the impartial arbiter, or edge of the coin. Essentially, then, we have a situation that is somewhat analogous to the adversary system in jurisprudence. It is the role and proper function of government to keep the diverse interests in check and in balance. In this way, the common environment can be protected from both the excesses of industrial irresponsibility and public panic.

Planning on the West Coast: north to south

The Pacific Northwest. In this region, notable (until recently) for its abundance of hydroelectric generation, we have the paradox of electric energy produced by the least polluting means of generation being used to supply power for the electroprocessing and aluminum smelting industries, which are notable for their abundance of pollutant by-products. But it is estimated that the demand for electric power in the Pacific Northwest will more than triple over the next 20 years. Meanwhile, the saturation point in future hydropower development is fast approaching (see Fig. 1). Present indications are that there will be a power crisis, beginning in the winter of 1971–1972, and a precarious imbalance may occur during the winter of 1976–1977.

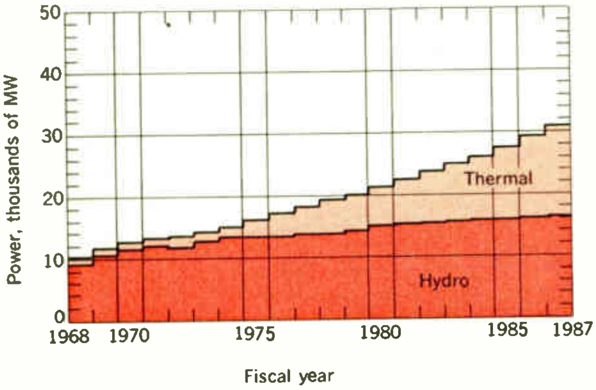
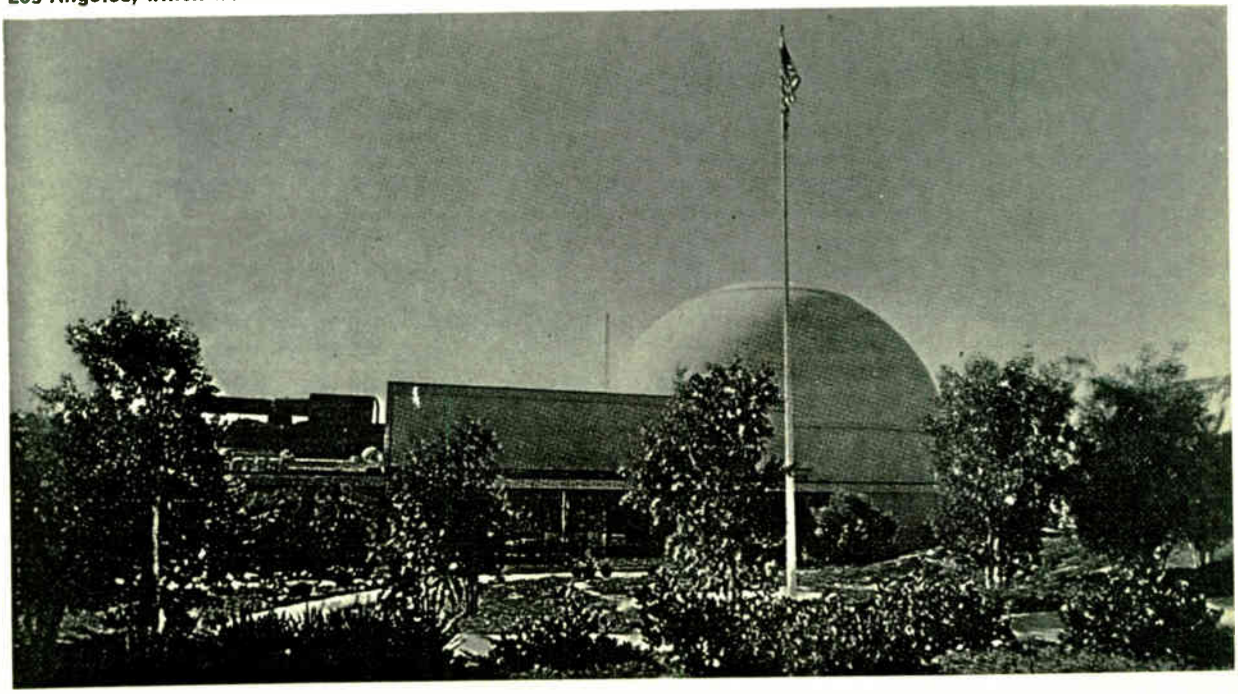


FIGURE 1. Graph of average firm energy resources in the Pacific Northwest area from 1968 to 1987.

To allay the coming emergency, the public and private utilities in Oregon and Washington, in cooperation with the federal government, have embarked upon a vast hydro–thermal power development program that will continue until 1990. The plans encompass the addition of at least 25 000 MW of firm power by the end of the 1980s. Under this 20-year program, increasing reliance will be placed upon thermal plants, particularly nuclear stations. Thus in the initial schedule, five nuclear and two fossil-fuel plants will put 7500 MW of power on the line between 1971 and 1980. Over this same time slot, additional hydrogeneration facilities could raise the generating capacity by an additional 6000 MW.

But the course of this ambitious power development plan is proving to be far from smooth. Mounting impact from environmental groups and public reaction may force some considerable revisions in the scheme. At a hearing last July, conducted by the AEC on Portland General Electric Company's application for a construction license to build its 1130-MW Trojan plant on the lower Columbia River, critics of the project alleged that the state of Oregon has never established a policy on the siting of nuclear plants, and has left such site selection to the discretion of the utilities. The leading question of the plant's opponents was: Is it wise to locate Oregon's first nuclear power reactor only 42 miles (67 km) from downtown Portland, the center of a metropolitan area of one million people? They urged, in the interest of prudence (in the event of an unforeseen accident), that the plant be

FIGURE 2. View of Southern California Edison's 450-MW San Onofre Nuclear Generating Station, 100 km South of Los Angeles, which went into service in 1968.



placed in a sparsely settled area of eastern Oregon.

Although the Trojan plant had the initial approval of the State Sanitary Authority after the utility company agreed to build a cooling tower to limit the effects of thermal pollution, it appears that the AEC's final decision will be delayed by a few months.

Another nuclear plant—an 1100-MW facility scheduled for completion in 1976—sponsored by the Eugene Water and Electric Board, was voted down by the local citizenry in a primary election charter amendment; it, in effect, prevents the city of Eugene from spending $225 million in revenue bonds for nuclear plant construction until after January 1, 1974. Also, a proposed nuclear reactor for the Washington Public Power System has run into public resistance and the utility may be forced to relocate the proposed site from the Puget Sound area to eastern Washington.

To compensate for the scratching of the Eugene facility from the program, the Joint Power Planning Council announced a speed-up on the installation of an additional 500-MW generator at one of Pacific Power and Light's existing fossil-fuel plants.

In summary, it is apparent that even the once power-rich Pacific Northwest is experiencing the growing pains of a forced rapid expansion—coupled with the attendant problems of finding satisfactory alternative means to its traditional hydrogenerating base—in its effort to prevent this huge industrial and agricultural region from becoming a twilight zone.

Southern California. Some 1000 miles (1600 km) to the south of the area just discussed, Southern California Edison Company provides electric service to more than 7 million people on the fastest-growing population region in the U.S. Over the next ten years this utility is committed to build an additional 11 000 MW of new electric capacity at an estimated cost of about $6 billion. The company is acutely aware of its dual responsibilities: preserving the environment and providing adequate and reliable electric service to its customers. But, like many other utilities throughout the country, the firm finds "plant siting the most challenging and frustrating problem the electric industry has encountered for decades." Because of the industrial and population explosion in its service area, Southern California Edison's expansion needs are greater than in most other regions in the U.S.; electrical peak demand on the SCE system is doubling about every *eight* years.

Nevertheless, the company's efforts to expand have met with vigorous public opposition. Controversial construction plans in the Southern California counties of Ventura, San Bernardino, and Orange—as well as in the states of New Mexico and Nevada—have been blocked. These adverse actions have caused extensive delays in building, the forced acceptance of stringent regulations to obtain construction licenses, or the loss of proposed plant sites. As an alternative way to meet increasing power demands, SCE has turned toward distant generating resources. Public resistance, however, has developed against even such remotely located projects. Residents of these areas oppose power plants because they feel that their own resources should be used to serve their local needs. And many who live along the routes of the proposed overhead transmission lines that would be required to transport the electric energy to Southern California cite esthetic reasons for their opposition.

But despite these objections, SCE is placing new generating units in service in New Mexico and Nevada, and has completed agreements that may pave the way for a huge new power complex in southern Utah. The utility has also initiated long-term purchases of power from the Oroville-Thermalito Dam project in northern California, and is importing power over the Pacific Intertie from the Northwest.

SCE emphasizes that it cannot "maintain reliable electric service to customers and locate all future plants in distant areas from population centers in Southern California where the electricity is used." In a recent company publication entitled "Edison and the Environment," the management says:

"Power from . . . remote sources must be brought to our customers over long-distance, high-voltage transmission lines. These facilities often cover hundreds of miles and are vulnerable to damage from storms and other mishaps which remove them from service.

"Therefore, every time we build a plant site far removed from Southern California, the potential risk of power curtailment and electrical interruptions increases accordingly."

Another factor in power station planning is the availability of adequate cooling water at sites where the least harm will be done by thermal pollution. For this reason, most of SCE's plants are situated along the coastline, where seawater can be used for this purpose. In other areas of pollution control, the utility cites its ten-year campaign to import natural gas to California (an effort that was vetoed by the FPC). And SCE claims to be the first utility company in California—and one of the first in the U.S.—to use low-sulfur oil in its steam-electric stations, and to have led the effort to get federal quotas eased for the importation of this fuel from Indonesia.

According to the company, SCE's total investment in "clean air" research and air-pollution control, since the early 1950s, adds up to more than $25 million. Further, the utility believes that it contributes less than one percent of all air pollutants in the Los Angeles Basin, and that its research in nitrogen oxides has produced a number of technological breakthroughs to reduce the emissions of this pollutant from 14 to 8 percent in the same geographic area. Finally, the company announced last January a major commitment to nuclear power generation by the awarding of contracts for the construction of two huge nuclear reactors to supplement the existing 450-MW San Onofre Nuclear Generating Station (Fig. 2) south of San Clemente.

The Midwest: action at Commonwealth Edison

Commonwealth Edison's service area (Fig. 3) is unusual in its balance between city–suburban and farm, trade and commerce, and large and small industry. Its load growth projections to 1975 range from a low of 10 percent in rural and farm areas to a high of 160 percent in the highly industrialized Lake Michigan shore perimeter complex. In the wide corridor running south from the Wisconsin border to below Joliet, this growth often exceeds 100 percent. In Chicago itself, load growth, under the stimulus of steel industry expansion and a spate of "superskyscraper" construction (ranging upwards of 70 stories), is considerable.

The present generating capacity of the Commonwealth Edison system is about 12 000 MW; it is operating on a 15

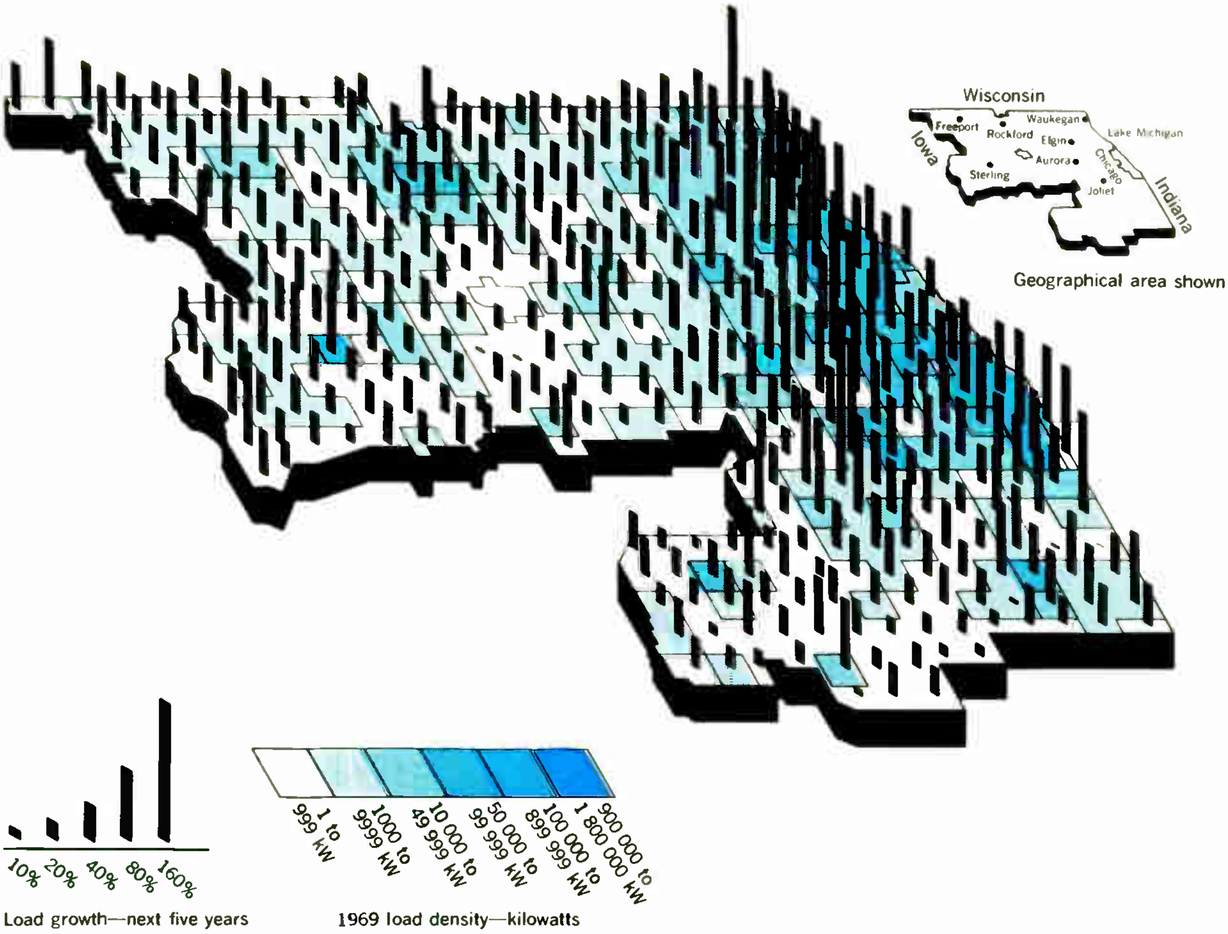


FIGURE 3. Map of Commonwealth Edison's service territory in northern Illinois, showing both the huge loads presently served and the strong future growth pattern of this utility. The color shading indicates the kilowatt demand by townships during the 1969 summer peak load; the bars show the percentage of load increase expected by 1974.

percent reserve on paper, 7.8 percent actual. By conservative estimate, the base-load capacity will be more than 16 000 MW by 1977.

Early in its history, Commonwealth Edison had the foresight to situate its coal-fired stations serving Chicago well away from the center city. This decentralized pattern placed the bulk of the generating facilities in low-population-density outlying areas, on the perimeter or outskirts of Chicago. Thus today, when one visits Commonwealth Edison's offices on the 38th floor (which affords a fine panoramic vista of the city) of the First National Bank Building in downtown Chicago, many of the utility's generating plants are visible in the distance. The smoke shade from these stations (see Fig. 4) is usually overshadowed by the emissions from the surrounding heavy industry or municipal incinerating plants. And the policy of the company, as recently stated by its board chairman, J. Harris Ward, is to situate all future generating complexes well away from urban areas.

Nuclear power program. This Chicago-based utility has presently under way the largest nuclear generating program in the U.S.; one that will, by 1977, generate almost 8000 MW (or about 50 percent) of the company's total capacity. Commonwealth Edison's Dresden No. 1 plant (200 MW) was the first privately financed nuclear power station in this country. The nuclear station projects, to be completed in successive stages, with the final target date of 1977, include

1. Dresden No. 2, 814 MW; located near Morris, Ill.
2. Dresden No. 3, 814 MW.
3. Quad-Cities, two units, each at 814 MW; located on the Mississippi River near Cordova, Ill. (Iowa–Illinois Gas and Electric Company has a one-quarter interest in this station.)
4. Zion, two units, each at 1100 MW; located on Lake Michigan, near the Illinois–Wisconsin border.
5. LaSalle County Station, two units, each at 1100 MW.

The utility, however, particularly at the Zion station now under construction, is experiencing opposition from both conservationist groups and the Department of the Interior. Power from Zion, scheduled to go on the line in 1972, could be delayed beyond that target date and this, according to the company, could result in blackouts in 1972 and 1973 because of "design alterations to the plant without ecological advantage, and at great expense."

The Zion operation will draw subsurface Lake Michigan water from offshore, heat it about 20°F (11°C), and discharge it again from an offshore outfall line. The utility claims that the method of discharge will drastically restrict the area in which temperature is raised 5°F (about 3°C) or more over that of the surrounding waters, and that this proposed system fully satisfies standards established by the State of Illinois (and approved by the U.S. Department of the Interior only two years ago). But on May 7 of this year, Interior proposed that the temperature of the water discharged to the lake be no higher than 1°F (0.6°C) above that of the intake waters. If this proposal is adopted, the company feels that it "would have a drastic effect on life in the Midwest." If applied to existing facilities, the policy "would shut down or require the modification of many industrial plants . . . and all sewage and electrical power plants on Lake Michigan." Although the utility has applied to the State of Illinois for a cooling-water discharge permit at Zion, the state is withholding action until Interior clarifies its latest proposal. Therefore, the status of this plant, insofar as service scheduling is concerned, is temporarily in limbo.

Efforts in combatting pollution. Commonwealth Edison began the installation of electrostatic precipitators back in 1929, and all coal-fired boilers in its metropolitan area stations are equipped with them. Since 1960, 47 coal-fired boilers have been phased out, and by the end of 1970, only nine will remain in service in Chicago. Like most midwestern and eastern utilities, the Edison system employs a mix of fossil fuels—coal, oil, and natural gas—plus a steadily growing percentage of nuclear capacity, which the company believes will drastically curtail air pollution.

The utility is now carrying out a sixfold scheme to implement the improvement of the environment. These new measures include

1. The purchase of 4.1 million tonnes of low-sulfur coal for use in existing coal-fired stations. (Most of this fuel will be obtained from Colorado, Montana, and Wyoming.)
2. Plans to install demonstration sulfur-removal processes at State Line (Illinois–Indiana) and Will County generating stations.
3. Increased use of natural gas for power generation. (During 1970, almost one billion therms of natural gas will be substituted for 4.5 million tonnes of coal—a 50 percent increase over 1969.)
4. A $22 million expansion of gas- and oil-fired peaking capacity facilities to expedite the retirement of coal-fired boilers.
5. Conversion of the Ridgeland Station (Fig. 5) from coal to low-sulfur oil. (The Department of the Interior has granted the company's request to import 4.5 million barrels of oil for this purpose.)
6. A $150 million budget for environmental control facilities under the utility's $2.25 billion construction program for 1970–1974. (This budgetary allocation will include funds for cooling ponds to preserve the quality of water, and for building new precipitators and for upgrading existing installations of these devices.)

In a recent news conference, Mr. Ward stated that "the new measures will enable Edison to meet the newly effected standards for sulfur emission of the Chicago Air Pollution Control Ordinance, and will substantially improve air quality as related to overall company operations."

The utility emphasizes, however, that measure no. 1—the purchase of low-sulfur coal—was not easy to fulfill; and this fuel will not be easy to burn, primarily because

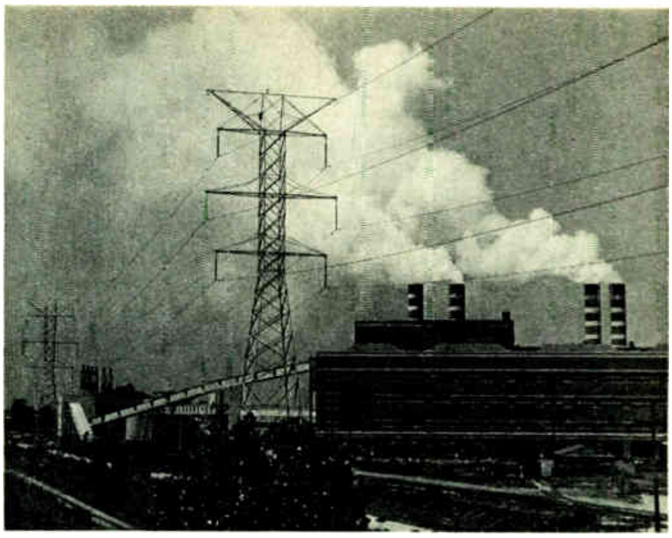
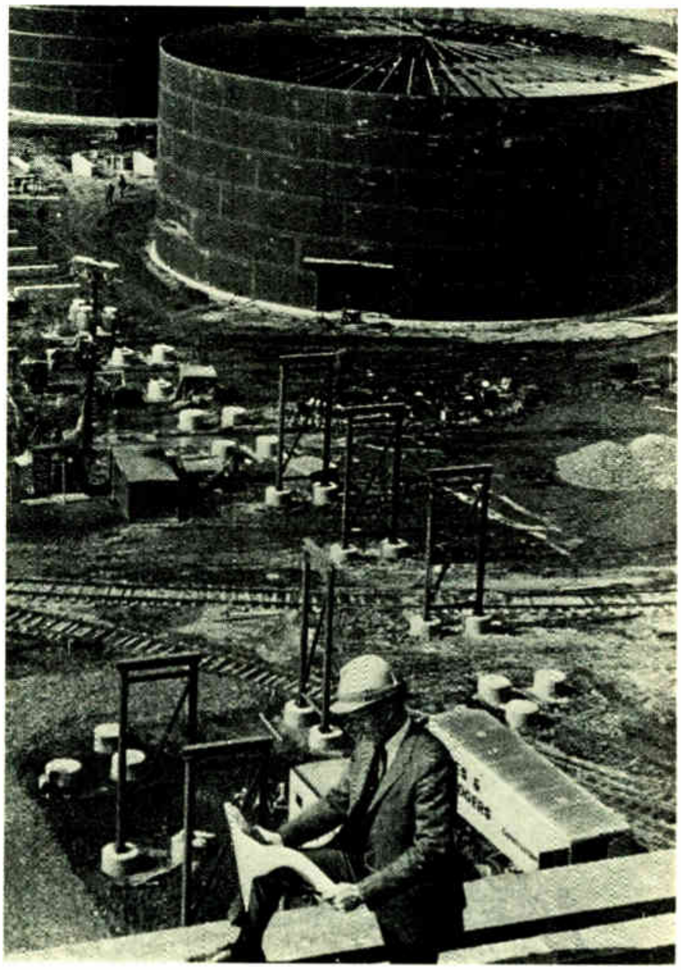


FIGURE 4. Comparison of smoke emitted by the Metropolitan Sanitary District of Chicago plant (right foreground) with that of Commonwealth Edison's Ridgeland Station (group of six stacks in left background). The emissions from the Sanitary District's plant are from burning vast amounts of greases collected in the sewage system, which serves 6 million people.

FIGURE 5. Construction superintendent on Ridgeland Station conversion project checking work progress from roof of this power plant, which is being converted from coal to the burning of low-sulfur oil. In the background are two of the four 4-million-gallon (14-million-liter) new fuel-oil storage tanks.



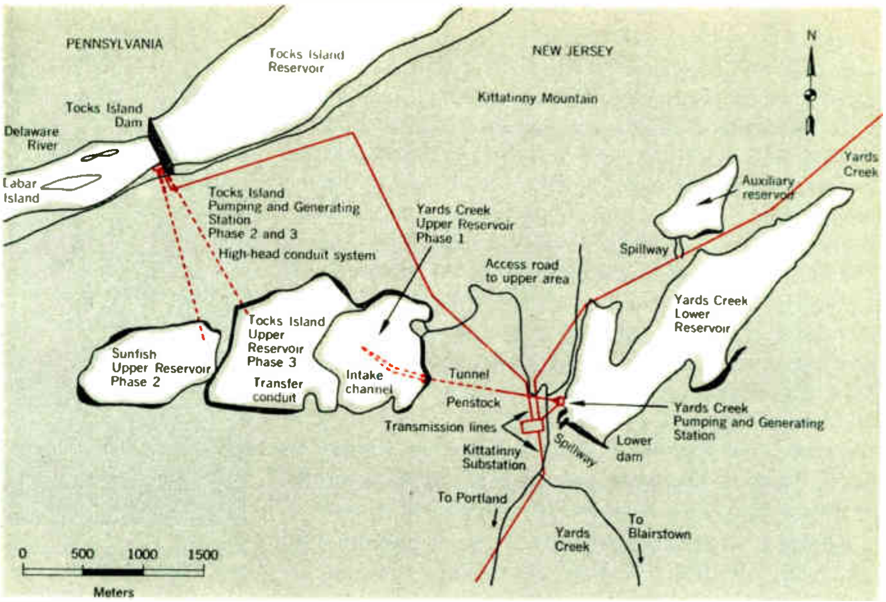


FIGURE 6. Map showing all three phases of the proposed Kittatinny Mountain project near the Delaware Water Gap. (Project is a joint venture of Public Service Electric and Gas Co. and Jersey Central Power and Light Co.)

the existing boilers were designed to accept Illinois coal and its particular burning and ash characteristics. And, in addition to modifications to the furnaces, steps are being taken to procure adequate railroad equipment needed to haul the new fuel from mines more than 1000 miles (1600 km) distant.

An 'environmental council' is established. Last spring, Commonwealth Edison announced the formation of an environmental council composed of 12 outstanding professional people—physicians, educators, and scientists—who will assist the company in formulating policies and implementing programs of action to benefit the environment. The new advisory panel, which will be autonomous and serve without compensation, will study and evaluate the utility's operations associated with the use of land, air, and water, and will recommend measures to minimize detrimental environmental effects. According to Mr. Ward, the advisory council "will keep a critical eye on our operations and set guidelines for us to follow in conserving natural resources and improving the quality of life in the communities we serve."

Midsouth to Midwest: American Electric Power

American Electric Power, which serves a seven-state area from Kentucky to Indiana, is recognized by the power industry as having one of the most efficient and fully integrated systems in the U.S. It has a mix of hydro, pumped storage, and steam plants and, like other major utilities, is planning for a large expansion of its generating capacity.

The backbone of AEP's transmission is its 765-kV network (scheduled for completion in 1972), which will extend through portions of five states. It will be capable of carrying more electric energy than any other grid in the world. The new network will establish higher levels of service reliability, flexibility, and integrity of electric service.

The expansion program—and some problems. American Electric Power is planning to install a total of about 12 000 MW of additional generating capacity during the next eight years; 2200 MW will be nuclear and the remainder, fossil fuel. The company would also like the go-ahead to build its proposed 1800-MW Blue Ridge pumped-storage plant on the New River (a tributary of the Kanawha River) in Virginia.

But AEC's expansion plans are running into difficulties in both the nuclear and the pumped storage areas. At the Cook Plant, which is presently under construction on the southeast corner of Lake Michigan, plans call for two 1100-MW nuclear reactor units with cooling water discharge into the lake. Although the intake and discharge lines at Cook are carried well offshore (800 meters), and AEC's flow studies indicate a minimal thermal heating effect, the Department of the Interior is now applying the same criterion that was mentioned in connection with Commonwealth Edison's Zion station.

The utility feels that uniform federal regulations and standards should prevail and apply to nuclear plant design and construction at the outset of the project. As matters now stand, the utility industry is threatened with both federal and state regulations. Further, AEP feels that it is unfair to have arbitrary new regulations imposed as a prerequisite for operational licensing after construction of a plant is well under way. Under the original schedule, the first unit at Cook was to be on the line by the end of 1972; the second unit, by late 1973. The company fears, however, that the present impasse may retard these projected dates.

But all is not going swimmingly on AEP's pumped-storage project either. Although the company believes that the increased low flow augmentation in the Kanawha produced by the Blue Ridge plant will be beneficial in controlling water pollution from nearby industry, conservationist groups allege that the proposed flow rate might destroy the fishing resources of that stream.

Other environmental efforts. The special design of AEP's 765-kV transmission lines permit agricultural land use along the route since the towers are spaced out to only three or four per mile (1.6 km). And because many towers can be erected by newly developed helicopter tech-

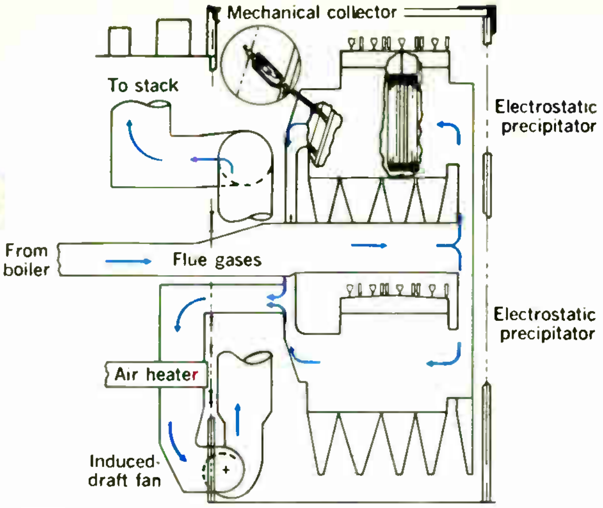


FIGURE 7. Cross-section diagram of the new electrostatic precipitator installed at Con Edison's Ravenswood unit 3, showing how the flow of furnace gases is handled. The precipitator is designed to remove oil ash or coal ash.

niques, unsightly timber slashes can be avoided in some areas.

The company has long advocated tall stacks for dissipating emissions from fossil-fuel plants, and it holds the record height for such single stacks, 1200 feet (366 meters).

Two eastern utilities

Public Service Electric and Gas. This New Jersey utility presently generates more than 6500 MW of firm power for its customers in the northern part of the state. By 1980, the company estimates that its capacity must increase to 14 000 MW. Right now, 55 percent of its generating station boilers are oil-fired, 35 percent use coal, and 10 percent are natural-gas-fired. Public Service, a pioneer in acquiring natural-gas turbine generating units for peaking and emergency service, has a capacity of 847 MW in these facilities. The company also has a reserve of 330 MW from its Yards Creek Pumped-Storage Generating Station (phase I of the Kittatinny Mountain project), which was put on the line in May 1966. The utility's plans for the second and third phases of this project—the development of Sunfish Pond and the Tocks Island Dam and reservoir (see Fig. 6)—would provide an additional 1300 MW to both the Public Service and Jersey Central Power and Light systems. But, as was mentioned last month in Part I of this article, these latter power and recreational area developments are under fire[1] from local residents and conservation groups. As a passing indication of the controversy over the projects, there is a sign on the National Park Service's information booth overlooking the Delaware Water Gap that reads: "In a land already rich in historic and natural resources, man is shaping a recreation area full of opportunities for the refreshment of body, mind, and spirit." A few miles from this spot, however, is another sign bearing a differing sentiment: "No more shad, oysters, farms, forests . . . Eat an engineer for lunch, tomorrow. Nix on Tocks!"

Public Service officials state that the utility has always complied with all state and local laws regarding air- and water-pollution controls, and will continue to do so. In its effort toward improving the environment, the company's policy is to switch from coal to natural-gas fuel during temperature inversions. The company estimates that between $6 and $7 million has been spent on the installation of electrostatic precipitators in its fossil-fuel plants. But company spokesmen admit they may have difficulty in complying with some proposed stringent federal laws on pollution.

As a further step in its pollution-control program, the company has appointed a Director of Environmental Affairs who is presently forming the nucleus of a department that will be concerned with all forms of pollution abatement and control. In this context, Public Service cites its 20-year water-pollution-control program, part of which includes the chemical treatment of all water before its ejection into a stream. And the company's "water pollution task force" has an excellent record of cooperation with the state in acting upon such problems as they arise.

In the southwest corner of New Jersey, Public Service is building its 700-MW Salem Nuclear Generating Station along the Delaware River. The site is about 40 miles (64 km) from Wilmington, Del. The company is naturally concerned about the problem of thermal pollution in connection with the eventual operation of this nuclear station. Fortunately, however, the problem is somewhat mitigated by the fact that the Delaware River broadens into a wide estuary in the vicinity of the plant site. Nevertheless, the company's engineering staff, assisted by marine biologists and environmental experts, is conducting a detailed study of the potential thermal effects by means of physical and mathematical modeling.

Consolidated Edison of New York. In May of this year at the annual stockholders' meeting, Louis H. Roddis, Jr., president of Con Edison, estimated the summer peak load demand on his company's system at 7725 MW, an increase of 375 MW over 1969. He predicted (with a high degree of accuracy in retrospect) that "a prolonged hot spell and unusual mechanical difficulties could require us—on few occasions—to reduce voltage, or to ask our customers to conserve power . . ."

This utility has been beset by expansion difficulties for the past several years. Because of construction delays on its Indian Point No. 2 nuclear plant, it has had no increase in base-load generating capacity to meet the rising summer demand. Thus, as a stopgap measure, the utility is installing 1800 MW of gas-turbine generation in various areas of New York City and in Westchester County to bring its total up to about 2000 MW in this type of generation. The turbines, however, are not designed for base-load operation. Because of their high operating costs, they can be used only for peak loads and emergency situations. The situation in reference to some of Con Edison's other projects in its ten-year program were discussed in Part I of this feature.

Back in 1966, the company began to upgrade the efficiency, where necessary, of its old electrostatic precipitators. There are six now in operation, including an unusual new unit (which will be subsequently discussed) on its 1000-MW Ravenswood 3 machine. The company claims to have invested $70 million for the purchase and installation of these devices, which will remove up to 99 percent of all particulate matter from stack emissions.

A new type of hot gas precipitator was placed in operation on the huge Ravenswood machine in 1967. The

"The only way we will know what the odds are is by continuing to accumulate experience in operating [nuclear] reactors. There *is* some risk, but surely it is worth it. . .Scientists and the public should be prepared to face the possibility of a nuclear incident just as we expect major earthquakes that will exact a large toll in property and lives. . ."

—*Walter H. Jordan, Assistant Director, Oak Ridge National Laboratory*

"While we are continuing to 'accumulate experience,' is it really wise to locate Oregon's first nuclear power reactor only 42 miles [67 km] from the Portland City Hall, the center of a population of 1 million people. . . ?"

—*Editorial reply in July 6, 1970, edition of the (Portland)* Oregon Journal

device, which can function when the boilers are either coal- or oil-fired, is designed to remove both oil and coal ash from furnace gases. As shown in Fig. 7, flue gases go directly from the boiler to the electrostatic section of the precipitator at temperatures of 650°–700°F (343°–371°C). The mechanical section of the precipitator functions *after* the electrostatic portion in order to remove any fly ash that might be reentrained in the gas flow during the rapping of the plates. [In the conventional precipitator, the flow of the flue gases is from the boiler to the preheater, then to the mechanical portion of the equipment, and finally on to the electrostatic section of the precipitator, at temperatures of 250° to 350°F (121° to 177°C).]

The advantage of having the gases enter the electrostatic section at the indicated higher temperatures is that the minute particles of fly ash have more conductivity at this range and can be captured more readily. Also, the collected oil ash is easier to handle because the gases are kept cleaner and drier by the higher temperatures and the arrangement of the collection equipment. The mechanical part of the precipitator functions by changing the direction of flow of the gases and by using centrifugal force to drop out the particles; the electrostatic portion works by having an electric charge placed on the particulates in the gases. The particles are then attracted to collecting plates and deposited. The plates are periodically shaken or rapped so that the collected particles will drop into hoppers for removal.

The Ravenswood device handles a gas flow of 4.3 million ft^3/min (120 000 m^3/min). It stands 175 feet (53 meters) high.

The company's efforts toward other aspects of environmental improvement are described under the following italicized headings:

Sulfur dioxide and sulfur reduction. In mid-1967, Con Edison signed long-term contracts with three suppliers—two in West Virginia and one in Pennsylvania—for a continuous supply of low-sulfur coal at an annual rate of 3.63 million tonnes. And, according to Con Edison, all coal and oil burned by the company was down to a sulfur content of one percent or less by April 1968—three years ahead of the then-existing legal requirements. (The utility is now required under New York State law to burn 0.37 percent sulfur oil in all new fossil-fuel plants.) The company also received FPC approval in 1968 for increased allocations of natural gas to replace some of the coal and oil it was then burning. Thus the amount of natural gas burned in 1969 increased by 28 percent. This fossil fuel is particularly desirable since it contributes the lowest amount of sulfur dioxide and particulates to stack emissions.

Con Edison states that the reduced use of coal and an increased burning of natural gas and low-sulfur oil, in combination with its high-efficiency precipitators, has decreased particulate emissions by 53 percent since 1967. According to the latest report from New York City's Air Resources Department, the company now contributes only 9 percent of the total particulates released to the city's atmosphere.

Although the utility is continually reviewing all new techniques for the removal of sulfur from coal and oil fuel either before combustion or from stack emissions after combustion, it feels that, to date, technologically feasible processes have not been developed for application to its large-scale operations.

Finally, the company is committed to a program of phasing out its older and less efficient generating stations in New York City as new facilities are put on the line and its spinning reserve margins become adequate to ensure peak demand capability.

Liquefied natural gas. The increased demand for natural gas by utilities and industry has produced a supply crisis simply because new domestic reserves have not been adequately developed. To circumvent this shortage, Con Edison is investigating the use of liquefied natural gas (LNG) from sources outside the continental U.S. LNG, a relatively new development, is maintained at −260°F (−162°C) with a resulting 600-fold reduction in volume. The gas is stored in this state until needed, when it is vaporized for use in boilers.

Nuclear power and pumped storage. At the present time Con Edison's nuclear generation represents only 3 percent of its total electric energy output but, by 1980, this amount will be increased substantially with the scheduled construction of more than 3000 MW of nuclear capacity. The utility believes that nuclear power for base load, supplemented by an additional 2000 MW from its proposed pumped-storage facility at Cornwall for peaking power, represents the ideal combination and long-range solution for meeting the ever-increasing energy demands of New York City and suburban Westchester County. And the company offers this scheme as the ideal answer in drastically decreasing its contribution to conventional air-pollution problems.

Water quality programs. Back in 1964, the Alden Research Laboratory of Worcester Polytechnic Institute built for Con Edison a scale model of the Hudson River area adjacent to and including the intake and discharge channels at the Indian Point No. 1 nuclear station. Since that time, models have also been constructed for that station's second and third units. The models simulate tidal, temperature, and flow conditions in the river, as well as the volumes and temperatures of cooling water discharged from the units. Results of these studies indicate what temperature distributions in the river will be. Thus it is predicted that the 2 million gallons per minute (7.6 million liters/min) withdrawn from the river as coolant will be returned to the stream about 14°F (7.8°C) warmer. The modeling indicates that the resulting temperature distributions will be within government standards established to protect the river's ecology.

As an additional factor of safety, however, four more sets of studies have been undertaken:

1. Northeastern Biologists, Inc., Rhinebeck, N.Y., conducted river temperature surveys near Indian Point No. 1 in 1966 and 1967, when the plant was operating at almost maximum capacity. (The results were used to prepare a mathematical model to verify the fact that thermal discharge criterions will be met.)

2. Texas Instruments Inc. has completed an aerial infrared thermal survey (this technique was described in Part I) of the Indian Point area of the river upstream to the Bear Mountain Bridge and downstream to Croton-on-Hudson; and the Raytheon Company is continuing with similar studies. (The information obtained is also being used to verify the indications of the mathematical model in predicting the ability of the Hudson River to dissipate waste heat.)

3. A comprehensive Hudson River ecology study was initiated in June 1969, and it is partially directed toward what the effects of waste heat discharges will be on marine life.

4. Additional independent ecological studies in the Hudson River are being made to determine types of biota and their characteristics, and the chemical composition and turbidity of the stream in the vicinity of Indian Point.

The utility will also initiate a hydrological, meteorological, ecological, and radiological study survey in the vicinity of David's Island at the western end of Long Island Sound. This island has been proposed as a future site for up to four nuclear units. Con Edison has formed an advisory board, consisting of prominent ecologists, educators, and engineers, for consultation on the matter of fish kills in the Hudson River in the area of Indian Point, and the possibility of such incidents in connection with the proposed pumped-storage plant at Cornwall. The company has pledged to restock any fish killed by the operation of these plants.

> "A blanket of poisoned air smothered the East Coast last week [week of July 26, 1970], and the strongest weapon any of our institutions responded with was rhetoric. It has become abundantly clear that those who hold power in this country don't give a damn for the lives and health of the rest of us."
>
> —*Dennis Hayes, National Coordinator for Environmental Action*

An 'encapsulated report' on 40 electric utilities[2]

It is, of course, impossible in a two-part series to present a comprehensive review of the pollution-control and -abatement programs presently under way at all of the major electric utilities in the U.S. In lieu of this, we refer the reader to the table on pages 70–72 of the June 1, 1970, issue of *Electrical World*, which offers a highly condensed glimpse of what 40 of these companies are doing toward the conservation of our common environment.

Role of government

There is apparently no consensus within the power industry on the role of government—at all levels—in the enactment and enforcement of anitpollution control legislation. Some utility spokesmen favor uniform federal codes and standards as the way in which to eliminate the confusing—and often contradictory—layers of state, interstate, and local ordinances. Others in the industry, however, fear the effects of harsh federal enforcement of tough antipollution laws enacted under the pressure of public alarm. And these people cite the good cooperative working relations that their companies have with state and local agencies in complying with existing pollution-control regulations.

Nevertheless, state agencies and commissions, as we have seen in the Pacific Northwest, are running into increasing opposition from conservation groups, ecologists, and the general public; and there is considerable pressure being exerted for the creation of superagencies, composed, among others, of environmental experts, that will have final decision-making authority on controversial environmental issues. An example of the effect of public criticism is the new—

Environmental code for utilities in California. The California Public Utilities Commission (which has been under fire from conservationists for alleged laxity on environmental matters) recently announced a series of regulations directed toward "protecting the environment."

The new rules require electric utilities to apply for the commission's authorization before constructing any generating stations or transmission lines of 200 kV and higher. Such applications must be filed at least a year before a ruling by the commission is required.

The commission also informed the utilities that they must make available to the public, on an annual basis, a 10-year forecast "of anticipated electricity requirements and the generating and transmission facilities planned to meet those needs." Further, the utilities must issue a 20-year projection biennially.

The commission's regulations also direct the utilities to notify various local and state agencies whenever they apply for new lines or generating capacity. (Formerly, the only notification required was to the state's coordinator of atomic energy development and radiation protection when a nuclear generating station was proposed.)

Under the new rules, utilities under the commission's jurisdiction cannot begin the construction of major facilities until the agency considers the impact of the proposal on "air, water, land, and other esthetic, environmental, and ecological requirements of the public and its energy needs."

Methods and systems for reducing stack emissions

Last year the power industry in the U.S. was responsible for discharging about 7×10^6 tonnes of sulfur dioxide into the atmosphere. And utility spokesmen generally concede that the major portion of all SO_2 emissions is contributed by fossil-fuel generating plants. The use of low-sulfur coal and oil and natural gas will, of course, reduce this annual level substantially. But the availability of these fuels is limited; and, as the reserves become exhausted in the future, the recovery of sulfur—on a feasible and economic basis—from more plentiful fuel resources, will have to be seriously considered.

An article entitled "Clean Power from Coal," by Arthur M. Squires,[3] in *Science*, offers the thesis that the "combustion of coal in the presence of a desulfurizing agent and the generation of power by a combination of gas- and steam-turbine cycles represent, together, a major opportunity" to do just that.

Pulverized fuel: a historical review. Since the mid-1920s, all of our major coal-based generating stations have used pulverized fuel (PF) for the firing of boilers.

In this fuel technology, about 60 percent of the coal's inorganic matter leaves the combustion chamber as fly ash, which, as we have seen, is usually collected by electrostatic precipitators. Some utilities claim efficiencies of more than 99 percent* for such devices installed in metropolitan area power plants.

Schemes to control fly ash and sulfur emissions from PF combustion have their roots in F. Winkler's basic patents (see Fig. 8), filed in Germany in 1922 and in the U.S. in 1928. His concept was to step up the rate of vertical gas flow through the granular fuel bed to and beyond the point at which each coal particle was suspended by the rising gas. At this point of "zero gravity" upon the fuel, the particles flowed freely, and the bed took on the aspect of a boiling liquid. This procedure was later termed "fluidization" by combustion engineers. The chemical or elemental composition and percentages of the gaseous effluents—carbon monoxide, carbon dioxide, carbon monoxide, hydrogen, and nitrogen—are indicated in Fig. 8.

In the 1950s, Albert Godel hit upon the idea of fluidizing a bed of coal on a traveling grate (Fig. 9) in what he termed an "Ignifluid" boiler. He also made the discovery that virtually all coal ash is cohesive at a temperature of about 1100°C, regardless of how much higher the ash-softening temperature might be. This fact permits the burning of coals (up to 2 cm in size) of various quality and composition in the fluidized bed. In this principle, as ash is released during the coal combustion, it agglomerates, drops to the grate, and is conveyed to the ash pit. The gases leaving the bed are primarily carbon monoxide (CO) and hydrogen sulfide (H_2S). As secondary combustion air is admitted to the space above the coal bed, the CO and H_2S are oxidized to CO_2 and SO_2, respectively.

In applying the Godel development to power plant boilers, Babcock-Atlantique (France) has installed an Ignifluid boiler system for a 60-MW generator unit in Casablanca, Morocco, and negotiations are under way for its use in conjunction with a 275-MW unit in Pennsylvania.

It should be noted that the system is applied primarily for the removal of fly ash, not sulfur oxides, from the stack emissions.

High-pressure combustion. The British Coal Utilisation

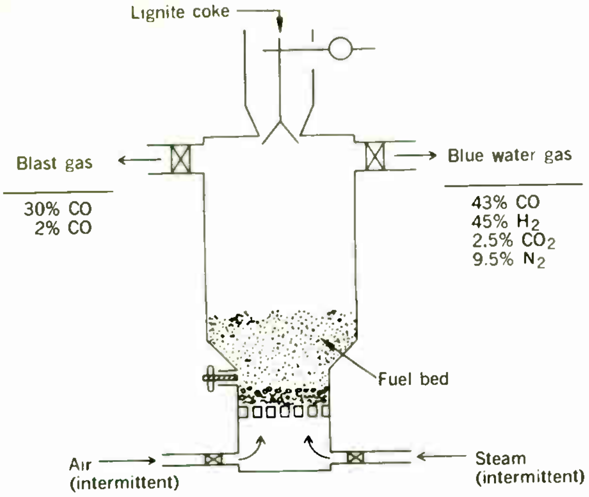


FIGURE 8. Diagram of F. Winkler's concept for partial combustion (gasification) of coal in a "fluidized bed." This design was first patented in Germany in 1922.

FIGURE 9. Cross-section elevation view of "Ignifluid" boiler. This concept, which features a traveling conveyor grate, was developed by Albert Godel and Babcock-Atlantique in the 1950s.

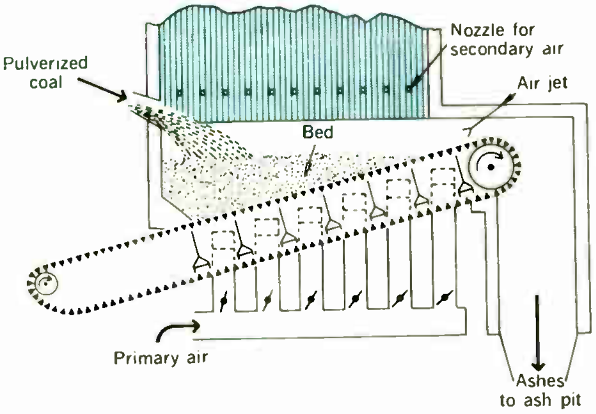
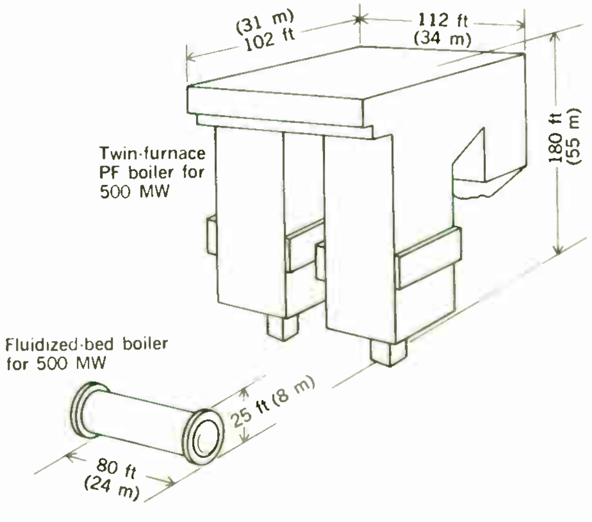


FIGURE 10. Projected comparison of the size of a possible fluidized-bed boiler fired at 15 atmospheres of pressure (left) with a conventional PF boiler, both for large-capacity power plant application.



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* The high efficiency of electrostatic precipitators is a function of the presence of SO_2 in the stack gases. As the percentage of SO_2 in the effluent is lowered, the electrical conductivity of the fly ash and particulates decreases—as does the overall efficiency of the precipitator. To handle fly ash from low-sulfur coal (according to Squires), the use of a precipitator will cost about $10 per kilowatt of capacity annually.

> "Unless the demands for clean air and clean water are kept in perspective—that is, unless there is a reasonable and fruitful union between industry and the environment—the antitechnologists and single-minded environmentalists may find themselves conducting their work by the light of a flickering candle . . ."
>
> —*Congressman Chet Holifield, Chairman, Joint Committee on Atomic Energy*

Research Association (BCURA) Industrial Laboratories, Leatherhead, England,[3] is presently conducting large-scale tests on fluidized combustion at 6 atmospheres of pressure and temperatures of about 800°C. Combustion under pressure, at elevated temperatures, is demonstrably more economical than conventional firing.

In the BCURA concept, hot gases from the fuel bed would be expanded in a gas turbine, which would provide about 20 percent of the system's power. The turbine, instead of wastefully discharging its exhaust gases into the atmosphere, would channel this heat into boiler steam production. Thus additional fuel economies would be realized. Figure 10 indicates the drastic reduction in boiler size that might be achieved by using the BCURA pressurized firing scheme. Further, no electrostatic precipitator for the capture of fly ash would be needed in this application.

Reduction of sulfur oxides, recovery of sulfur.[3] The National Air Pollution Control Administration (NAPCA) is exploring the possibility of using limestone or dolomite—which is essentially calcium carbonate ($CaCO_3$)—in a fluidized-bed boiler for the absorption of SO_2. Both the Westinghouse Electric Corporation and United Aircraft have been involved in aspects of this effort.

Tests conducted at atmospheric pressure indicate that considerably more $CaCO_3$ must be injected than the stoichiometric amount needed to react with SO_2 to form calcium sulfate ($CaSO_4$) if, for example, this control method is to satisfy New Jersey's requirement deadline of October 1971 for allowable sulfur oxide emissions.

We know that the world's reserves of oil and natural gas will probably be exhausted before those of coal. Thus emphasis on the future use of this latter fossil fuel is being placed in a new perspective. In this "Coalplex" schematic (Fig. 11), coal gases could be converted by chemical or combustion processes into both synthetic illuminating gas, for transmission by pipeline, and liquid fuel. Fixed carbon in coke, for example, can be desulfurized through the reaction of calcium oxide (CaO) with hydrogen gas and H_2S released by the coal distillation process of forming coke. (The FMC Corporation has used this method for producing a low-sulfur coke.)

Figure 12 is a block diagram depicting the process flow toward both clean power generation and sulfur recovery. It is a concept that is presently being explored at New York's City College.

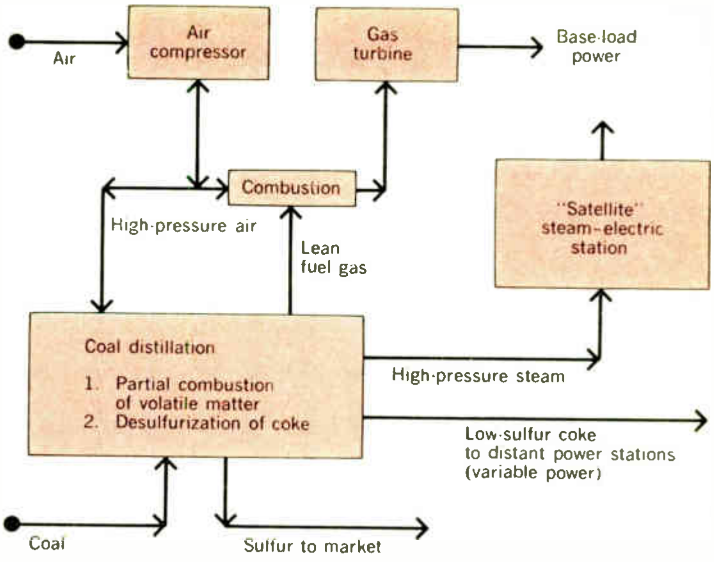
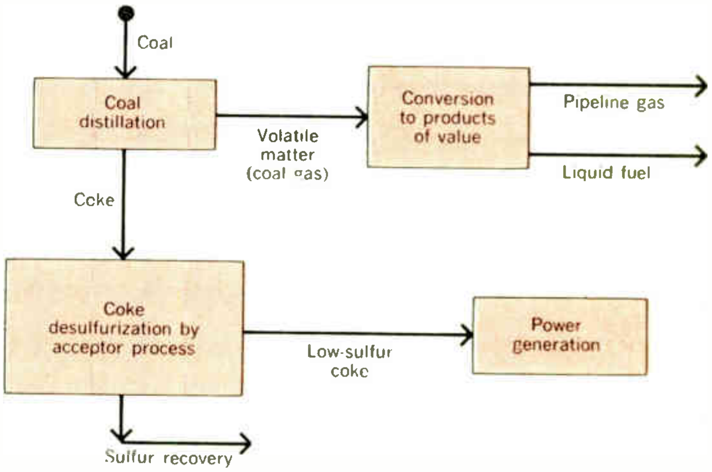


FIGURE 11. Block diagram of process flow in a proposed "Coalplex" scheme.

FIGURE 12. Block diagram of a "Coalplex" scheme for the generation of "clean electric power" and for sulfur by-product recovery.



A commentary in conclusion

The evidence of the writer's research for this two-part series has convinced him that the problems (and solutions) associated with environmental pollution control by the power industry are very large in scale and complexity. The industry has been jolted by widespread public reaction against its expansion (made necessary by our expanding economy), and many concessions will have to be made—by both factions—in arriving at equitable compromises. It is a time for candor and frank discussion by all concerned parties. We all share the same planet and the same environment; thus prudent courses of action, predicated upon sound scientific and technological methodology, should be applied in the public interest—which, in the long run, is everybody's interest.

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New product applications

Panel displays for numerical and alphanumeric readout are described in recent application notes

Designed for use in calculators, computers, and data terminals, a new panel display, available in 8- to 16-digit versions, is called Panaplex.

The alphanumeric, dot-matrix display system with 256-character capacity has been named Self-Scan. A miniature panel display for 16–18 digits is also available.

A 12-position display panel for the Panaplex system is shown in Fig. 1; the drawing in Fig. 2 shows the simple sandwich construction. The panel is basically a cold-cathode, gas-discharge, multidigit display tube. There are nine cathode segments per character, but the panel can be operated as either a 7- or 9-segment display. The 9-segment arrangement makes it possible for all numerals in the display to be equally centered (in a 7-segment display the numeral 1 must be off center to the right or left). Characters are formed by illuminating the appropriate combination of cathode segments. In addition, each digit position may have a decimal-point cathode, a comma cathode, or both, as shown in Fig. 2.

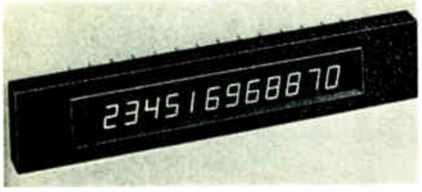
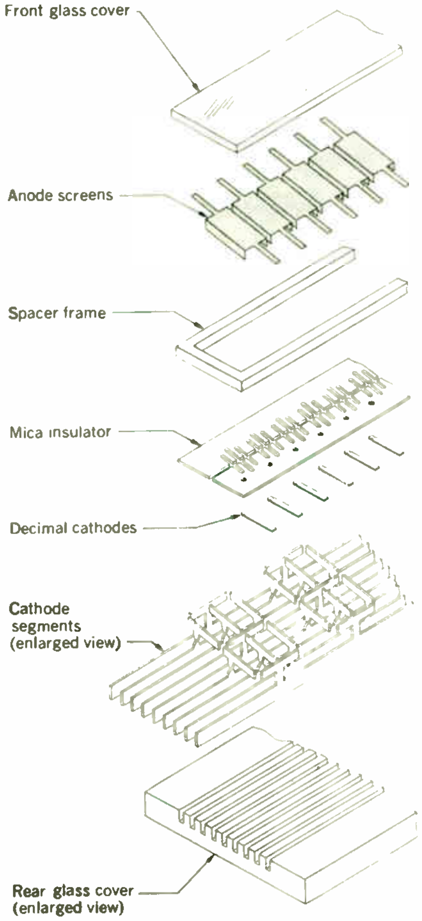


FIGURE 1. Panel display for calculators.

FIGURE 2. Panaplex construction.



This type of panel display is operated in a multiplexed mode in which the cathode drive and decoder circuitry is time-shared by all the digits that are displayed.

The block diagram for a typical 9-segment, 16-digit display system is shown in Fig. 3. The electronics required to operate the display are the anode driver, the cathode decoder, and drivers. The rest of the circuitry depends on data source and other system electronics.

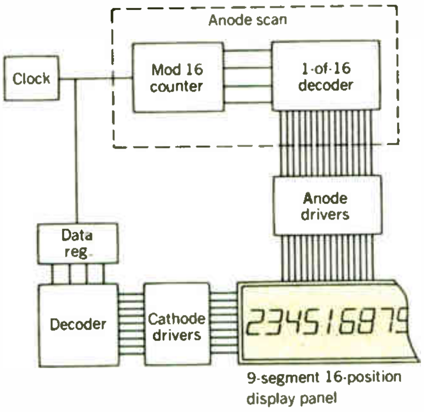
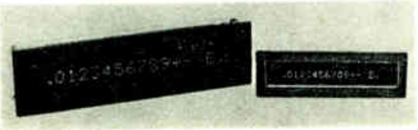


FIGURE 3. Typical driving system.

FIGURE 4. Dot-matrix types of displays.



Operation in the time-shared mode means that each digit is ionized in sequence until all digits have been operated. Strobing can be in either direction and scanning is usually at a rate above 60 scans per second to appear as a continuously energized multidigit display.

The nature of the Self-Scan dot-matrix display is shown in Fig. 4 with the miniature version at the right. It is also possible to show graphic information in dot-matrix format, particularly in the larger panels.

An exploded view of a Self-Scan panel is shown in Fig. 5. In operation the panel can be thought of as comprising three basic sections: glow scan, glow priming, and glow display. The rate of scanning is 60 Hz.

Application notes on the two panel display systems and one on timing requirements are available from Burroughs Corporation, Electronic Components Division, Plainfield, N.J. 07061.

Circle No. 85 on Reader Service Card

FIGURE 5. Exploded view of Self-Scan.