IEEE spectrum

## features

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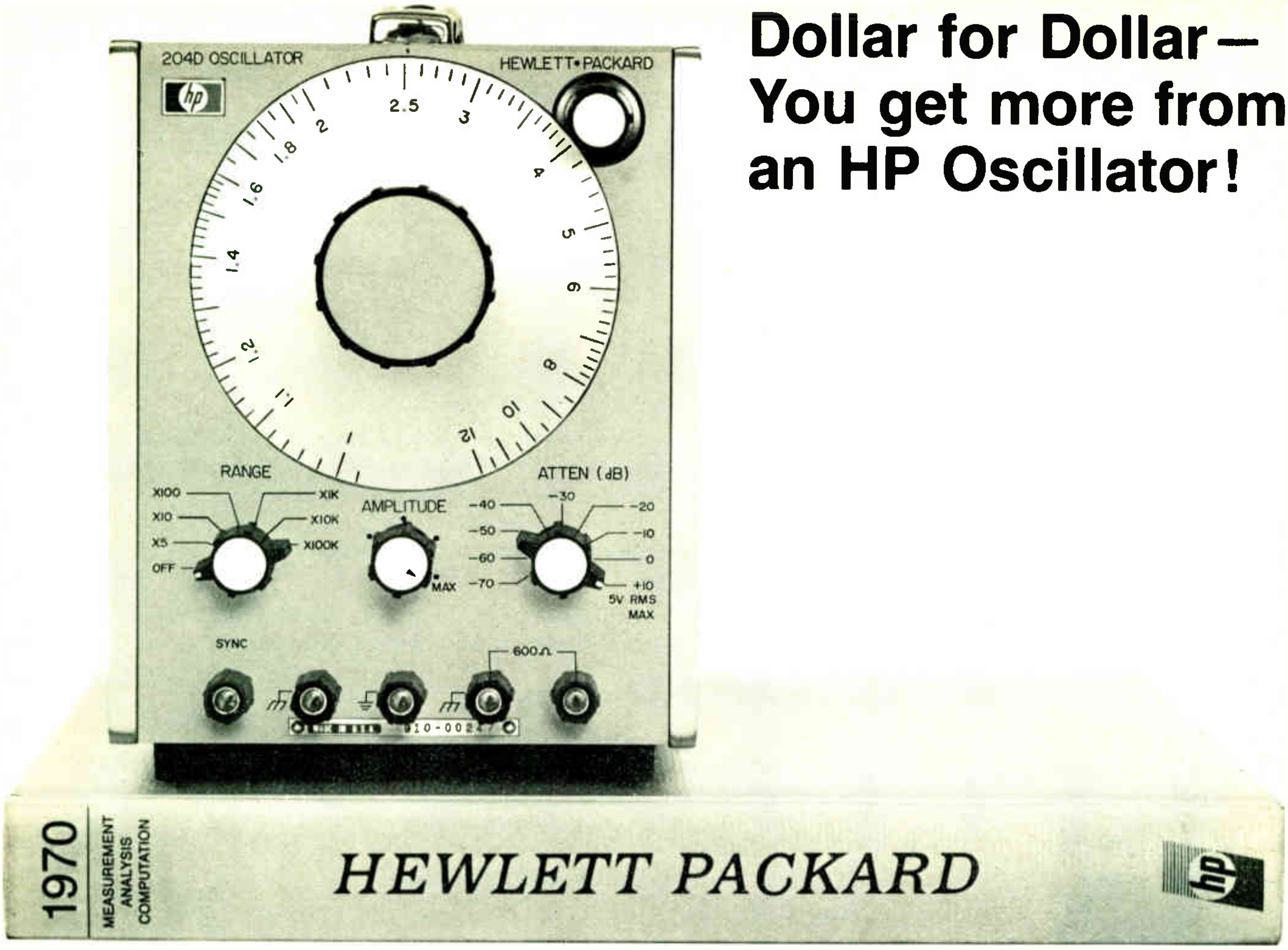


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SIGNAL SOURCES

## the cover

*Hydropower! Churchill Falls, Labrador, renamed in 1965 after the late Sir Winston Churchill, tumbles 75 meters into the gorge below. The cataract, higher than Niagara Falls, is the most dramatic feature along the 320-meter descent of the Churchill River (over a distance of about 32 km) from the Labrador Plateau. The Churchill Falls development will harness this energy at the largest hydrogenerating plant in the Western World. See the story that begins on page 81. [Photo courtesy of Churchill Falls (Labrador) Corporation Limited]*

## departments

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.





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# Forum

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

## Leadership challenged

This open letter is directed to the IEEE, AIAA, and SCI Boards of Directors, since they represent the management of the major professional societies to which I belong. It is also directed to the membership of these organizations, since my thesis should interest them.

What do many members of these organizations have in common? Careers that, directly or indirectly, are dependent upon aerospace/defense contracts that advance the state of the art in electronics, aircraft, avionics, computers of all kinds, as well as simulation of all kinds, to mention a few. As my fellow members in all three organizations are successful in advancing the state of the art in these fields, we also help to keep our nation at the forefront of technological advancement in a host of satellite industries and arts. This, in turn, is one of the few avenues left open to us, in an increasingly competitive world economy, where productivity increases are greater than labor's usual wage (increase) demands.

What have all of you been doing while one of the most incredible debates was taking place these last few weeks in the U.S. Congress on the fate of appropriations for the proposed supersonic transport (SST)? You have been wringing your hands in frustration and proclaiming your impotence on the important subject (Congressional debate) to your membership "because our tax-free status as nonprofit scientific–technical–professional societies would be revoked" if we deigned to engage in such crass and mundane activities as lobbying in Congress for research and development programs such as the SST. Our combined membership must surely contain well over 95 percent of all of the knowledgeable experts on supersonic transport; yet, as organizations we must remain mute! The careers of literally thousands upon thousands of our members now, and in years to come, may depend upon the favorable vote of the Senate on the SST appropriation bill, and what do you do? One of you, I am embarrassed to report, holds a seminar for unemployed aerospace technologists, in which, among other inanities, our unemployed members are advised "not to clear their throats or to pull up their socks before answering a question" in a potential employment interview.

I submit that the so-called tax-free umbrella, under which you hide every time there is a need for strong, political lobbying that only our organizations can do effectively to protect our members' interests, is the biggest red herring pulled on us since the so-called impenetrability of the sound barrier. In the first place, in order to worry about taxes, you must be operating profitably. If we are not operating profitably (which, I believe, is the present situation), then we certainly need not fear the retribution of the tax collector. Furthermore, if one of my organizations is operating at a surplus, may I ask why page charges have been instituted in its journals, why the quality of our journals is deteriorating, why headquarter's staff and budgets have been slashed, and why my dues go inexorably upward? It is obvious that there are no profits to tax, except artificial ones that we, the membership, may create by paying dues that exceed the cost of services rendered, by writing for our journals without charge to them (indeed, sometimes paying for the privilege to write), and, most important, by donating our services free of charge to the many committees, meetings, technical conferences, and publications from which any profit—if it exists at all—must come. The only other advantage of our tax-exempt status is that our members' dues are then deductible from their income tax liability.

Yet in the name of preserving the profit, which may be squeezed (literally) from the unpaid sweat of our member's labor, you, the Boards of Directors, will sit in complete paralysis, as one of the most forward-looking and peaceful technical challenges of recent times, the SST, goes down the drain. Instead of trying to preserve the status quo, why don't you use your considerable intellectual and business skills in Congress to advance positive arguments for all programs that place our members' careers at stake? This is a positive social good, for if the nation does not continue to fund research and development contracts at a volume greater than it has in the last few years, we shall have no alternative but to impose wage, price, and tariff controls on our economy. The driving force for technological innovations (our only way of effectively competing with the rest of the world) will be severely reduced, if not altogether crippled. If our organizations did lobby for science/technology programs, I am certain our members would not object to the loss of the tax deduction, if that became necessary.

Finally, if you cannot lead, if you find it too arduous and onerous to change our organizations to do in the political arena what they alone can and must do to protect and enlarge the careers of our members, then I ask all of you to resign collectively from the leadership of my organizations. I also call on those of my fellow members, who will put in the time and effort in the job of reorganizing us, to deal effectively with those "know-nothing" forces in our society that seek to dismember the scientific, technological body of our society. I ask my fellow members to join me in the reshaping of our professional organizations to better suit the needs of our membership in these unusual times.

*Arthur I. Rubin*, Princeton, N.J.

(See "Spectral lines," page 41)

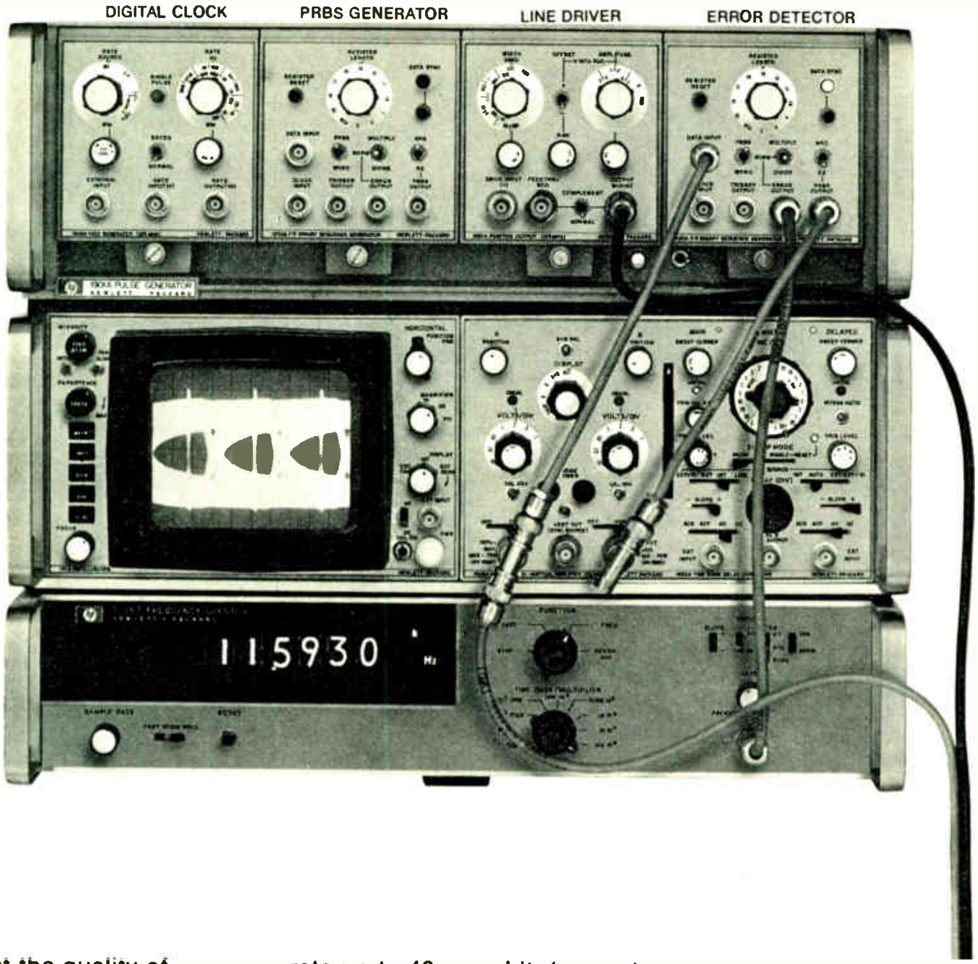
## Manuscript reviewing policy

It seems to be IEEE policy, although I do not know of explicit rules requiring it, that manuscript reviewers for the *Proceedings of the IEEE* and the various *IEEE Transactions* are unknown to the manuscript author. This policy is undoubtedly necessary for the survival of the review procedures.

It also seems to be generally true that a manuscript reviewer is given the name of the author. I suggest that this is bad policy. Its only advantage appears to be a personal one for the reviewer; he has the assurance that he is unlikely to make a serious mistake by approving the paper of a well-known author or rejecting that of an unknown one. We pay a high price for his comfort, however.

Let me illustrate this by a recent encounter I had with the review process. In a manuscript I submitted to one of the *IEEE Transactions*, I mentioned in passing that the one-dimensional Schroedinger equation is not satisfied by the form $\cos(kz - \omega t)$. This is from Schiff's *Quantum Mechanics*, but is so elementary that it was not referenced. I was amazed when a reviewer asserted that the cosine form does satisfy the equation. Since the *IEEE Transactions* editor assured me that the reviewer is "internationally prominent," I can only conclude that his review was hasty. Would he have been so careless if I

# The new way to measure bit error rate: HP's pseudo-random binary sequence generator




081/6

How do you test the quality of a digital transmission system? By feeding in data, and comparing what comes out with what you put in . . . right?

You can do this by hooking up a scope to the output, and looking at the "eye" pattern. The accuracy of your results depends on the randomness of your signal, however . . . and even at best, there's still an element of estimation involved.

That's why HP has developed the 1930A—a new plug-in for the 1900 Pulse Generator System. The 1930A is designed specifically to solve digital system testing problems. It enables the 1900 System to generate over 70,000 different apparently-random binary sequences ranging in length from 7 bits up to 1,048,575 bits . . . at any desired rate up to 40 megabits/second. And this means a better "eye."

The 1930A's capabilities don't stop there, however. By using two synchronized 1930A's, one at each end of your transmission system, you can **directly** compare output with input. Every time there's a discrepancy between the pattern coming in over the transmission line and the pattern being generated by the 1930A at the receiving end, the "receiving" 1930A sends out an error pulse.

Add a counter, and you're measuring bit error rate **digitally**. No more guesses.

Another use for the 1930A's is to scramble and unscramble data where security is important. Data can be coded in over a million different ways and no complex synchronization is required to unscramble.

The 1930A is digitally programmable, as is the entire 1900 System. Price of the 1930A is only $1200. For applications where a 16-bit word generator will suffice at the transmitting end, HP's 1925A may be substituted for the 1930A, at a savings of $350.

For further information on the 1930A, or on any aspect of the 1900 Pulse Generator System, contact your local HP field engineer. Or Write Hewlett-Packard, Palo Alto, California 94304. In Europe: 1217 Meyrin-Geneva, Switzerland.

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had been a well-known author, or from a major university? I cannot be certain, but I believe that the reviewer would assume the correctness of the statement, on the grounds that an authority would not be wrong about a statement so easy to verify. At least he would spend three minutes to check the statement, acting on the assumption that the paper would be published and should be verified in all details.

I have reviewed papers for one of the *IEEE Transactions*, so I recognize both sides of the question. When time is short and work piles up, the temptation to review a manuscript on the basis of the author's reputation is great. I doubt that this is the best review method, however.

Most reputable authors publish only when they have something to contribute, but on all of us the pressure to publish in order to enhance the prestige of our institution is considerable. When this pressure is coupled with the "review by reputation," the result is that some of our *Transactions* turn away good papers and publish papers that are slight variations of those published twice elsewhere.

I believe that IEEE should adopt for its technical publications a review procedure that keeps an author unknown to the reviewer, just as the reviewers are unknown to the author. This would decrease the number of repetitive papers that we have to wade through and improve the quality of the papers that are published.

*Harold Mott, University of Alabama*

The review policy of *IEEE Spectrum* is, as Professor Mott assumes, to let the reviewer know who the author is and to reveal the identity of the reviewer to the author only in exceptional cases and with his consent. In my limited but intensive experience I have found *IEEE Spectrum*'s reviewers to be conscientious and unawed by authority. Every paper has been favored by a number of very competent reviewers who have read it carefully and commented in depth. Unless we really have the problem Professor Mott is concerned about we will not change the policy.

*David DeWitt, Editor*

## Correction

In response to W. M. Clark's inquiry about the article "Acoustic Communications Is Better than None" by Victor C. Anderson (*IEEE Spectrum*, October 1970, pp. 63–68), the author points out that the arrow marked "5 minutes on Fig. 6 should be vertical and is too short. Also, the 2000-fathom figure in the last paragraph on page 66 is somewhat in error. The 4500-meter depth is the correct one."

# Spectral lines

**A longer view.** There is significant unemployment (perhaps 10 percent) among IEEE members today and it is painfully concentrated geographically in certain areas of the United States. IEEE SPECTRUM and the IEEE leadership have been flooded with correspondence suggesting that the IEEE change its status and become an active advocate of the special interests of its membership. In particular the AMA is often suggested as a model. The letter by Arthur Rubin in this month's "Forum" is typical of many letters and suggests positive action to keep our U.S. members employed. If a sufficient fraction of IEEE members really want the IEEE to be their business representative, there are constitutional means to change our mission. However, lobbying to continue current aerospace and military work may not help much, since the existing lobbies of the aerospace and military industries are hard at work with limited success. How then should electrical engineers be employed?

A longer view starts with the concept of engineering as the profession that devises methods and things useful to people. We have become very proficient at the devising part and enthralled with the power of our techniques. The determination of the usefulness to people has been given little professional attention. Probably there can never be a precise calculus of usefulness but that is all the more reason to take the subject seriously, since we may never be able to set out unattended sensors whose data are used to make the monthly printout of optimally useful engineering missions. To many of us, the SST is very low in usefulness to people. The mechanism of U.S. representative government is responding to that conclusion. Similar conclusions have been reached about space travel. Military capability may well be next.

For the long run we had better apply ourselves to the things people really need. Our children should inherit a clean viable world with foreseeable and adequate supplies of food, water, energy, and raw materials. We need economic systems in which reasonable equity is provided without resort to strikes and slowdowns, which do not require exponential growth for their proper functioning, and which actually optimize the usefulness to people of their output. Health services must be made adequate everywhere and at the same time population must be controlled. The international military game must be phased out.

This is just a short list of some of the needed methods and things that are so useful that some might be called essential. There are tasks for many of us on that list, perhaps for most of us. There are two objections to the proposition that IEEE members should be working on these key problems:

1. Our skills do not match the needs.
2. No one is set up to solve those problems and is staffing up.

In answer to the first objection let us note that there is a full skill match only after a problem has been solved. Once a set of successful steps has been found, "skills" appear that greatly optimize each step and we solve the problem much better the second time. There was no "skill match" when we founded the semiconductor and computer arts. Our profession includes the people who found the solutions to problems that were being solved for the first time. That is our real skill.

The second objection is one the IEEE can act on as an organization of professionals. Of course, it is not true that no one is working on these problems, but it is not clear that the effort is at all adequate. We can evaluate the adequacy of activities devoted to such essential ends and make recommendations for their improvement. Out of these studies we will get a good idea of some of the skills needed and can develop a matched member retraining program.

How much better it is to lobby for a chance to serve people's real needs than to ask a subsidy for the SST because we know how to engineer it. *David DeWitt*

# Electronic noise:
## the first two decades

*Most of the basic knowledge in the field of electronic noise was gained in the 20-year period following World War I. A considerable amount of the vacuum-tube data obtained was later translated into the semiconductor language*

*John Bertrand Johnson**

*You could hear a pin drop.* (English saying)

*You could hear the grass grow.* (German version)

*Such harmony is in immortal souls;*
*But whilst this muddy vestment of decay*
*Doth grossly close it in we cannot hear it.*
(Merchant of Venice)

Fifty-two years ago the classical paper on noise in amplifiers was written by Dr. Walther Schottky.[31] The high-vacuum thermionic amplifier could then be called about six years old. Its development had taken place along nearly parallel lines in several countries, including Germany, mostly under rules of strict secrecy. It seems now almost incredible that out of the Germany of those years, faced with military defeat and economic collapse, could come a scientific paper of the quality and technical importance of this paper of Schottky's.

The amplifiers developed at the Siemens-Halske Works no doubt had the same kind of faults as those produced at other laboratories—poor welds, mechanical resonances, unstable cathodes, inadequate pumping, etc. These faults could distort the signals applied to the amplifiers and, since thermionic amplifiers were then being installed in commercial and military telephone systems, the faults became a technical liability. At this time I was employed in the Engineering Department of the Western Electric Company, the Engineering and Supply Division for the Bell System. I was assigned to study some of the many projects on vacuum-tube research, came early in touch with Schottky's work, and have some memories of the work that went on. With this as my background, the Editor of IEEE SPECTRUM asked me to write this article on the study of amplifier noise as I saw it develop during about the first two decades of its progress into a rather broad scientific field.

### 'Wärmeeffekt' and 'Schroteffekt'

In the 1918 paper, Dr. Schottky evidently assumes that the grosser current fluctuations produced by faulty tube structures such as those just enumerated have been, or can be, eliminated, and he is left with two sources of noise that are of a much more fundamental nature. One he calls the "Wärmeeffekt," in English now commonly named "thermal noise." This is a fluctuating voltage generated by electric current flowing through a resistance in the input circuit of an amplifier, not in the amplifier itself. The motion of charge is a spontaneous and random flow of the electric charge in the conductor in response to the heat motion of its molecules. The voltage between the ends of the conductor varies and is impressed upon the input to the amplifier as a fluctuating noise. This flow of energy between molecules and electric current involves not the charge of the electron but rather the rate of flow of power between charge and momentum. It involves the Boltzmann constant $k$ times the absolute temperature $T$ of the system, and a power flow of at least $10^{-17}$ watt to be audible in a telephone. Schottky believed any other noise source would be much stronger than this.

And here, for the sake of history, we may digress a bit. In estimating the total of noise that is going to be contributed by the "Schroteffekt," the integration of a certain expression is needed that has come to be called the Schottky equation. Schottky performed this integration

* John Bertrand Johnson (F) died at the age of 83 on November 27, 1970, the day he completed work on this manuscript. Dr. Johnson's obituary appears on page 107 of the January issue of IEEE SPECTRUM.

and got the result $2\pi/r^2$, where $r$ is a damping factor of the circuit, $r = R/L\omega$.

My recollection is that because of some postal delay the 1918 paper did not get to the United States until about 1920. On reading it, I became suspicious of the integration, but in the then-available tables of integration could find no solution for the Schottky equation. I asked my friend, Dr. L. A. MacColl, mathematician, for assistance. He suggested splitting the Schottky expression into four complex factors, integrating each separately and then recombining them for the final result, $2/r$. When, after much labor on my part, this was done, MacColl again looked at the equation and said this was a case for the method of poles and residues and, without putting pencil to paper, read off the correct result. This was impressive, but evidently the method had not yet penetrated down to physicists and engineers, and the more cumbersome method was left in. The method of residues was evidently used later by Fry[5] and by Hull and Williams,[11] but before them several other methods had also been suggested. We correctors, however, chose to abide by Schottky's word that the thermal-effect noise is much smaller than the shot noise, and recognition of the technical importance of the thermal noise was delayed by about a decade. This probably did not matter much, because it was a busy decade spent on other phases of the project.

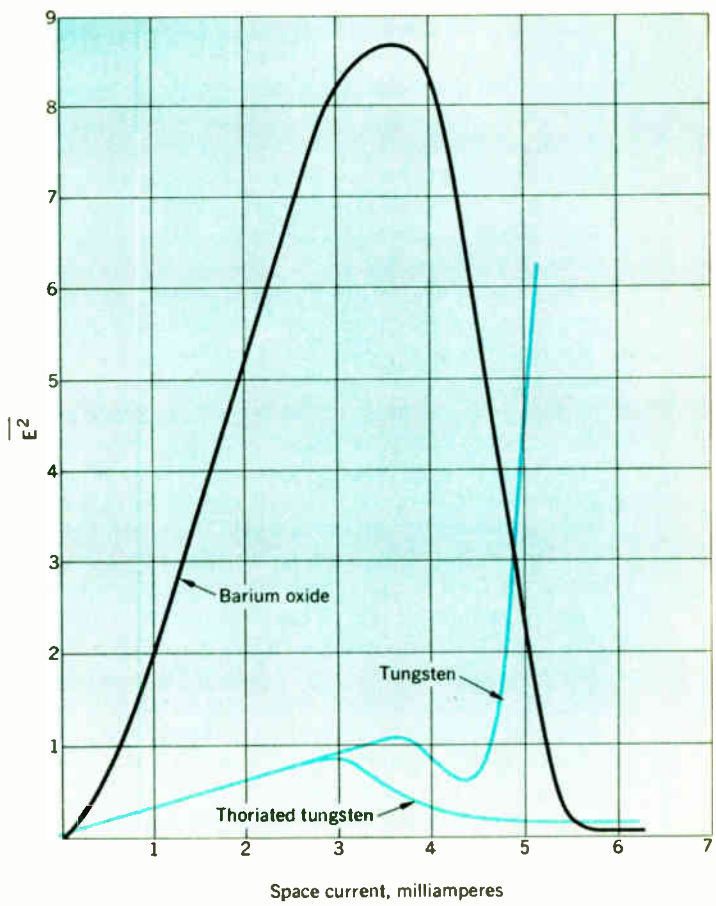
In the case of the "thermal noise," as we shall call it, the electric charge is in effect held in long bags with walls relatively impervious to electrons at low temperature. The mass transport of charge along the bag, or wires, under the influence of the heat motion, sets up the potential differences that generate the fluctuating output of the amplifier.

When now one end of the conductor, the "cathode" of the tube, is heated to incandescence, electrons can be emitted from the cathode surface to travel across the vacuum toward the anode. The electrons are emitted at random times, independent of each other, and they travel at different velocities, depending on initial velocity and voltage distribution for electron passage. In the case of a small electron emission, a small nearly steady flow of current results, with a superimposed smaller alternating current whose amplitude can be calculated from statistical theory. This small current flowing through the amplifier generates the "Schroteffekt," or shot effect, in the amplifier.

The first experimental work on identifying and measuring the shot effect was done in Schottky's laboratory and published by C. A. Hartmann in 1921. This seemed like a well-designed set of tests, but was a little ahead of its time in the new art. After corrections, it left little doubt of the existence of the shot effect.

The next step came with the publication of three papers in 1925. T. C. Fry[5] covered parts of the theory that he wanted put on a firmer mathematical basis. Through Fry, the work of Hull and Williams[11] at General Electric and Johnson[14] at Western Electric–Bell Laboratories became known to the participants, which may have given added impetus to the efforts. At GE, the first application of Hull's screen-grid tube in the amplifier increased the accuracy of the GE work to such a point that the value of the charge of the electron found by the shot effect came out close to that of the oil-drop method. The work of Johnson at lower frequencies revealed the existence of the "flicker effect," which could be many times greater than the shot effect, as well as the effect of space charge in reducing the magnitude of both shot effect and flicker effect by large factors (also recognized by Hull and Williams).

**FIGURE 1. The effect of space charge on fluctuation noise. Three tubes have filaments composed of tungsten, thoriated tungsten, and barium oxide. $\overline{E^2}$ is the mean-square noise voltage across the output measuring device expressed in arbitrary units. The variation in space current was obtained by changing the cathode temperature, the plate voltage remaining constant. (Copyright 1934, The American Telephone and Telegraph Co.; reprinted by permission)**



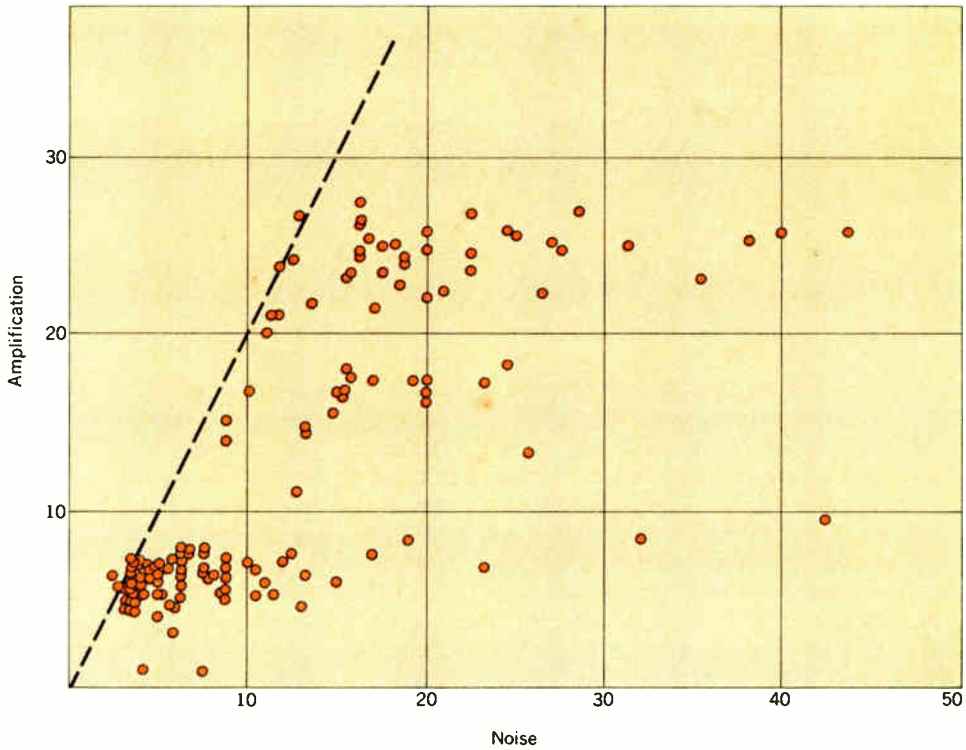



**FIGURE 2. Amplification as a function of noise in three-electrode tubes; noise in arbitrary units; each point represents a tube. (Physical Review, 1925, reprinted by permission)**

Each of these phenomenons will be discussed in connection with Fig. 1, which is reproduced from the 1934 paper by Pearson.[27]

By the early 1930s, the shot effect had been fairly well established for thermionic diodes, simple amplifiers, and photoelectric tubes.

A typical event that took place during the shot-effect work will be described here. We were visited by Sir J. J. Thomson, and the shot effect was demonstrated to him. Our explanation of it may not have been satisfactory, for as he left the room, the discoverer of the electron, with a forbearing smile and a gentle shake of the head, muttered, "Oh, no, no, no!"

Toward the end of the shot-noise work, a rough exploratory test was made. About 100 triode tubes of various kinds were picked out at random and tested for gain and noise in a circuit of fixed voltage, frequency range, etc. A resistance of 500 kΩ was connected across the input of the tube under test, with the output of the tube resistance–capacitance coupled to the amplifier. For each tube, the observed noise was plotted against the separately measured amplification of the tube, as in Fig. 13 of the 1925 article, here reproduced as Fig. 2. There is one point for each tube and these points are scattered over the right-hand side of the diagram. On the left, the point distribution stops abruptly along a straight sloping line. This suggests that along this line the noise pulses that the amplifier responds to have been amplified by the tube under test by its gain factor, from incoming pulses of more nearly constant value. Could this be the thermal effect predicted by Schottky?

A few simple tests, such as varying the electrical value of the input resistor, its temperature, its size, its material, soon answered the question in the affirmative. The results were discussed with Dr. H. Nyquist, who in a matter of a month or so came up with the famous formula for the effect, based essentially on the thermodynamics of a telephone line, and covering almost all one needs to know about the thermal noise.

### The two effects: A and B (or T and S?)

We have, then, two different sources of electrical noise obeying statistical laws. Both have the properties in common that the noise can be described as a power dissipated by the noise source at a point of the amplifier circuit, and that for frequencies above certain values the noise power is constant up to very high frequencies. For thermal noise this constant power extends also to low values, while for shot noise there are many exceptions and variations.

**T: the thermal effect.** By the Nyquist[23] formulation, the thermal effect may be expressed as a voltage applied by the source to the input point of the amplifier at the high-impedance grid-leak resistor:

$$\text{Thermal formulation } \overline{V_T^2} = 4kTR \qquad (1)$$

Here $\overline{V_T^2}$ is the mean-square noise fluctuation per unit bandwidth as measured by a thermocouple voltmeter; $R$ is the resistance of the input circuit; $T$ is temperature in degrees Kelvin; $k$ is Boltzmann's constant, $1.38 \times 10^{-23}$ joules/degree K. This can also be written

$$W_T = 4kT \text{ watts per unit resistance} \qquad (2)$$

per unit bandwidth. The total for any case is then obtained by linear integration over the resistance and bandwidth range.

There is not much more to be done with this formulation except to consider the slope resistance of the tube, which will be done later.

**S: the shot effect.** The Schottky formulation for the shot effect per unit bandwidth may similarly be written

$$\overline{J_S^2} = 2ei \tag{3}$$

or

$$W_S = 2eiR_1 \tag{4}$$

where the charge on the electron $e = 1.602 \times 10^{-19}$ coulomb; $i$ = dc space current, in amperes, flowing in space from cathode to anode (negative); $R_1$ = total resistance between cathode and anode, including that internal to the tube (function of frequency); and $W_S$ = power per cycle dissipated in $R_1$.

This formulation was found by the early workers to hold under some carefully controlled conditions, including choice of cathode materials, freedom from space-charge effects, and choice of frequency band. When these conditions were judiciously selected, the experiments yielded, for instance, very nearly the correct value for the charge on the electron, as was shown in the tests of the 1920s. More complicated effects were also observed; they were subjected to a rather concentrated theoretical attack in the 1930s and will briefly be described in the following paragraphs.

1. *The flicker effect.* With some cathodes there is superimposed on the pure shot effect a fluctuation in current that is much greater than the shot current itself. This is illustrated in Fig. 1. The linear portion of the curve, obtained from tubes having filaments of tungsten and thoriated tungsten, gives the values the pure shot noise should have. The noise data were recorded as the temperature of the cathode was raised, the plate voltage of the diode being supplied by a fixed battery through a constant resistance. A measure of the cathode temperature is given by the indicated total current, in milliamperes. In the barium oxide tube, the noise increased more rapidly and reached a maximum value approximately ten times that of pure shot noise. The reason for this excess noise was surmised by Johnson to be fluctuations in the work function of the cathode surface due to particle migration, and was discussed at length by Schottky, who called it "Fackelneffekt."

2. *Space-charge depression.* Still in Fig. 1, after passing through a maximum, the noise in all three of the tubes decreases toward values eventually far below the theoretical shot value, at first thought to be effectively zero. This is an important feature, for it is in this low noise range that thermionic devices can be used as amplifiers. Schottky ascribes this noise depression to the smoothing effect of a dense space-charge layer near the cathode—between cathode and grid in a triode, for instance—and he works out a plausible theory for it.

3. *Frequency and flicker effect.* With fixed operating conditions, except for the natural frequency of a narrow-band circuit that the device works into, the noise output depends on this frequency. Normally the noise varies with this frequency $f$ as

$$\overline{J_S^2} = f^{-n} \tag{5}$$

where $n$ may lie in the range 1.2–0.9, depending on the material and condition of the cathode. For very pure materials, this increase in noise may be unobservable at frequencies above a few thousand hertz. Oxide cathodes, and perhaps all cathodes, show the effect down to very low frequencies, such as perhaps one cycle per month, where the noise has merged with the natural drift of the device.

The $f^{-n}$ law has been discussed theoretically by Schottky and others.

4. *Ionic effects.* Ions may be generated from gas in the device, or from the electrodes, either by photoelectric or collision processes. The ion current would normally be small and make only a small addition to the dc electron current. But if, say, a heavy positive ion becomes trapped in the negative potential well that is created by the electron space charge, then a large pulse of electrons may be released through the potential minimum to make a noise pulse. This effect was described by Johnson[14] and studied by Ballantine[1] and others. The sharp rise of the noise at high currents as depicted for the tungsten tube in Fig. 1 is a result of ions emitted from its filament.

5. *Thermal noise in plate current.* A curious situation developed in about 1930. Llewellyn[21] suggested that the internal resistance $R_0$ of the thermionic device is really in parallel with the external resistance $R_1$, the parallel combination taken as the thermal noise source of the output circuit. Llewellyn suggested that this slope or differential resistance should be considered at the cathode temperature in combining it with the external resistance at room temperature. The result seemed to give reasonable agreement with observations.

6. *The half-temperature rule.* In making more careful measurements, however, Pearson[28] concluded that the temperature of the slope resistance should be half of the absolute temperature of the cathode in order to get agreement with Eq. (1) or (2). There seems at first to be no physical basis for this peculiar situation, but further experiments seemed to agree. Some found it hard to believe that there could be such a coupling between a stream of electrons and their source (the cathode). The most careful calculation of the effect, based on certain assumptions, was made by Rack,[29] who found that over a considerable part of the mid-temperature range the value of the temperature should be taken as $0.644T$ instead of $0.500T$. The most plausible explanation of the effect is probably presented by Schottky,[33] who arrived at about 0.500 for the factor, but his presentation has to do with a certain rectification of the noise signal in the output circuit of the device and is not easy to repeat here.

Another facet of the $\frac{1}{2}T$ rule is that for very small currents the noise can be derived from either the Schottky equation $ei$ or the Nyquist equation $kT$. This is in the region where the current to the anode is too small to set up appreciable space charge, because of too low a cathode temperature. This seems to have been first noticed by F. C. Williams,[42] but was also discussed by Schottky and others. The temperature must again be taken as $\frac{1}{2}T$, but tubes are probably not often used in these regions, except possibly for logarithmic response.

## Rating of tubes

We have, then, two fundamental sources of noise in an electronic circuit: thermal noise, which can be calculated from the input parameters; and shot noise, which is modified by various device parameters and can, in some cases, be calculated, or can be measured for individual devices. In the device, the effects of these sources are added into a noise-power spectrum. In a diode, this is fairly simple, but in a grid-controlled tube it is more complicated since each electrode must be considered.

Up to 1940, the period of this review, the method proposed by Johnson for grid-controlled tubes was followed closely by others. This technique involved short-circuiting the input, setting the other parameters at some operating condition, and measuring the noise at the output of the device in this condition. This was then considered the noise figure introduced by the device itself, and it could be expressed in terms of a resistance at the input that would give the same amount of thermal noise. This would normally be a few hundred to a few thousand ohms.

Several measurements of this kind will be referred to but no details will be given here because methods may have changed and, moreover, because most of the tubes tested are now obsolete.

Tests on a few U.S. tube types were made by Pearson,[27] whereas Moullin and Ellis[22] reported tests on some British tubes. Spenke[38] studied some German tubes, on which he presented extended and careful discussions. Probably the most extensive and detailed discussion and measurements on U.S.-made tubes for our period were reported by Thompson, North, and Harris.[41]

I would like to acknowledge some debts: for the short early days of my participation, three friends, long departed: Hendrick van der Bijl, Oliver Buckley, and Harold Arnold, for technical guidance and management support; for aid in the preparation of this manuscript, the staffs of Bell Telephone Laboratories and of Thomas A. Edison Industries; for love, cooperation, and understanding: in the early times, Clara, and in the latter days, Ruth.

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The following list of references is appended for readers who want to go a little further into the early history of our subject than is done in this brief review. It should help establish the approximate sequence of the important steps made in the first two decades. The list does not pretend to be complete, and it contains many items that are not specifically referred to in the main text.

By 1940 this basic work had been about completed, and from there on the work on noise took different directions. First, there was the highly mathematical study of how to extract a weak signal from a background of noise. Then came the transistor and the translation of the vacuum-tube data into the semiconductor language. This opened up new fields of applications, such as low-temperature work, rocketry, and space research. A few recent references may open the door to these fields.

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# If you are a concerned engineer . . .

***If you are not part of the solution, you are part of the problem. Here's how one organization provides the means for becoming part of the action***

**Harry C. Simrall** National Society of Professional Engineers

*The engineering profession must go beyond the purely technical realm if it is to assume a leadership role in the issues of our time. For the National Society of Professional Engineers, the challenges posed by the problems of social change, the economy, and the environment have provided the impetus for developing programs for the engineer who seeks "involvement."*

Since becoming president of the NSPE some eight months ago, I have traveled the length and breadth of the United States. I have talked with literally hundreds of engineers, both members and nonmembers of the Society, and I can report with all candor that the quiet giant that was once the rank and file of the engineering profession no longer sleeps. I found concerned engineers who are not content to sit on the sidelines and remain a part of the problem. Said one young NSPE member:

"As many of us in my age group view this situation, there is only one viable approach—only one road to take. There are simply no cop-out routes left. We, the engineering professionals, have either got to assume a leadership role in the major environmental and other basically technological issues of our time, or we are going to be clobbered."

Few doubt the need for strong technical groups, but many indicated to me that they had joined the NSPE, or would like to do so, because they believe that this organization has the potential to make a professionwide response to the problems and challenges that face the engineering community. Its three-level—chapter, state, and national—membership organization and its activity in the nontechnical phases of engineering commend it to these engineers.

An area in which they are most interested is government liaison, both the legislative process and the administrative decisions. They are also concerned with broad employment problems, ranging from the current concern with unemployment to representation in such particular employment problems as portable pensions, patent rights, and registration.

They are anxious for unified action in improving the image and status of the profession through public relations and guidance, ethics, and cooperation with other professional groups. They desire to participate individually in the decision-making process and to be a part of an organizational pattern that is effective at federal, state, and local levels.

## Government liaison

What is the NSPE doing today to confront the many issues of our time? To be effective in government liaison, the NSPE has its national headquarters in Washington, D.C., with offices located in the state capitals. At the national level an experienced staff maintains an alert for any legislative or administrative action with potential engineering consequences. During the two-year period of the 91st Congress recently concluded, over 25 000 specific pieces of legislation were introduced. These were reviewed by the staff and appropriate committees. The Society's views were presented on many, with improvements suggested where and when appropriate. Of course, support for the enactment of some was made, whereas others were vigorously opposed. An example of the former is legislation to provide relief from engineering unemployment problems incident to reductions in defense and aerospace production.

Introduced by Senator Edward Kennedy and Representative Robert Giaimo, the bill is entitled "The Conversion Research and Education Act of 1970." This legislation seeks to provide constructive alternatives for the use of engineering manpower by reorienting it to the resolution of the United States' serious social problems in such areas as housing, transportation, pollution, health, and crime. Enactment would declare as national policy that engineers have continuing opportunities for socially useful employment in positions commensurate with their professional skill; that the total federal investment in science and technology be raised to an adequate level of annual expenditures and grow in proportion to increases in the gross national product; and that federal spending for civilian-oriented research be increased to a level equivalent to defense-related research and development.

The Kennedy–Giaimo bill was supported by the Society because, for a number of years, NSPE has been urging the Congress to take some form of action to provide relief for those engineers who would be affected by manpower reductions in the defense and related industries. The Society also supported specific legislation proposing establishment of a National Conversion Commission. Most recently, the NSPE strenuously backed measures to authorize federal funds for research and educational programs intended to assist engineers, scientists, and technicians in reorienting their talents to other areas as the defense and space effort diminishes. At the same time, the Society has been conferring with members of the President's immediate staff for the same purpose. The need for remedial action at the federal level is more evident now than it has been for many years. Interest in providing for it will carry over into the 92nd Congress, and the NSPE will continue its efforts on behalf of unemployed engineers.

The mounting environmental problems of the nation have resulted in a substantial block of legislative activity. The NSPE presented testimony on bills to amend the Solid Waste Disposal Act to provide financial assistance for the construction of solid-waste disposal facilities and improve research programs; to establish an environmental financing authority having the power to purchase state and local bonds under certain circumstances; to alter the formula for allocating federal funds to states for waste treatment plant construction; to strengthen federal control over water pollution; to authorize increased federal program grants to state water pollution control agencies; to amend the Clean Air Act to strengthen the national effort for prevention and control of air pollution; and to establish an office of technology assessment for the use of Congress to aid in intelligent adoption of options involving effects of technology.

The clamor for continued national and international environmental controls can be expected to continue for some time, and the NSPE will maintain its vigil to insure sound legislation and other governmental action to promote cleaner air and water.

### Involvement

Involvement is a word that has taken on great significance in the past few years. Involvement is for those engineers who no longer want to be part of the problem, but a part of the action. Recognizing the painful conditions that exist in our cities, the NSPE in 1968 launched six community involvement pilot projects in geographically dispersed chapters around the U.S.—Newark, Hartford, Miami, Madison, Carson City, and the Lake Jackson–Freeport area on the Gulf Coast of Texas. In each undertaking, the chapter involved itself in a pressing local problem. These were areas in which engineering capability and approach would contribute a unique kind of expertise and viewpoint in transportation, crime, housing, pollution, and education and planning. The overall pilot program included marshaling total community support from government, educational institutions, professional organizations, and the news media.

So successful were the pilot projects that the Society decided to hold nationwide public affairs involvement workshops to instruct chapter representatives in taking a leadership role in hometown problem solving. Five workshops were held during 1970 in Atlanta, Los Angeles, St. Louis, Toledo, and Dallas. Held on university campuses, the workshops mirrored the national dialogue on major environmental and social problems. The scope of some of the topics covered by participants during the year included pollution abatement; off-shore drilling of oil wells; problems of airport location, noise, and pollution; water supply; sewage disposal; recreational development; racial integration; local flood control; zoning and land use regulations; and community relations.

The workshops, coupled with equally important follow-through action, prove that NSPE members have the enthusiasm and the desire to bring their collective talents to bear on local problem solving. They also generated a new wave of enlightened attention and a commitment to get things done. The year 1971 promises to push members even further down the involvement road.

The entire field of public relations and communications has always received high priority by the NSPE. National Engineers Week is in its 21st year, the recipients of the six annual journalism awards for outstanding newspaper writing on an engineering subject are about to be selected, and planning is now under way to name the outstanding engineering achievements of 1970 for the fifth consecutive year.

### Member benefits

For greater effectiveness in attending to the individual needs of the member, the NSPE some years ago established practice sections. Within these sections the engineer in industry, government, private practice, and education finds programs tailored to his particular interests. The sections provide the Society with the thrust needed to zero in on problems. A brief review of current activities will indicate the scope of their work.

The NSPE does not forget, nor does its Professional Engineers in Industry (PEI) practice section, that about 50 percent of all NSPE members are employed in the private industrial sector. Nor has it forgotten that unemployment has become a major problem in this group in recent months. With this situation in mind the Professional Engineers Employment Referral Services (PEERS) was initiated.

Under PEERS, unemployed members of NSPE may complete a short résumé form published in recent issues of the Society's journal, *Professional Engineer*, and mail it to NSPE. Each form will be assigned a code number and sent to a mailing list of 926 employers of engineers. At the present time, PEERS is a successful operation and has aided in placing many unemployed engineers in touch with prospective employers.

PEI has also been most instrumental in the establishment of the National Registry for Unemployed Engineers. PEI had frequent conferences with representatives of the Manpower Administration of the U.S. Department of Labor on planning ways to assist laid-off engineers. It was agreed that one effective way of attacking the problem would be through the establishment of an occupational registry. As a result, the new registry was installed in the office of the California Department of Human Resources, in cooperation with the NSPE. A central location is used as a repository for applicant profiles and employer personnel requests. Although PEERS is for NSPE members only, the registry is for all engineers who meet the Department of Labor definition.

In another activity of the PEI, an economic survey was made of the membership to identify areas in which the resources of the NSPE might be utilized to benefit the professional engineer. The results show a great interest in the problem of salary compensation, as well as in the total compensation package, including fringe benefits. The survey will aid the PEI greatly in formulating future programs.

For the Professional Engineers in Government (PEG) practice section, recent events have had special significance in that federal Executive Order 10988 was replaced with Executive Order 11491. Among other things, this change eliminated the types of recognition that federal agencies could grant to employee organizations. Participating organizations are now to be known as labor organizations. Under the old Executive Order, PEG had encouraged members to participate through professional-only groups sponsored by or affiliated with state PEG sections

As a result of this change, the NSPE Board approved a PEG recommendation that, in the event local groups of engineers find it necessary to continue operations under

E.O. 11491 as labor organizations, these groups will be constituted as fully autonomous affiliates, rather than as integral elements of the NSPE official organization.

Along with the National Federation of Professional Organizations, PEG has been cooperating with a special task force established by Congress to review the federal classification and pay systems and to recommend any changes that appear desirable. Although it is too early to predict the eventual outcome of the study or the fate of any legislation to which it leads, encouraging progress has been made.

A summary of Professional Engineers in Private Practice (PEPP) activities over the past six months indicates that a major portion of its time and resources are devoted to government-related activities and legal and judicial developments. It is encouraging to note the frequency and significance of involvement of NSPE–PEPP in federal agency decision-making at the invitation of the agencies themselves. Some of the major problems facing consultants at the moment are liability, competitive bidding, the threat of product boycotts, a possible Supreme Court test of the statute of limitations, environmental design jurisdiction, and construction cost control.

*Professionalism* is the word of the moment for NSPE's Professional Engineers in Education (PEE) practice section. The section, in a follow-up to the 1962 study of attitudes, practices, and procedures in engineering colleges and schools regarding instruction in professionalism, has arranged for the distribution of a questionnaire to all deans of engineering and department chairmen in accredited schools or colleges in the United States. It is hoped that the returns will give a current picture of activities in this area of instruction.

**Professional development.** NSPE has fought long and hard for its four-point program for on-the-job professional development:

*Recognition and status as a professional.* In too many cases, persons performing technical work below the professional level are referred to as engineers or scientists.

*Improved utilization of engineering talents.* Many companies find it a matter of good economics, improved efficiency, and good business practice to relegate many assignments previously performed by the professional engineer to technicians or preprofessionals.

*Economic remuneration.* The professional engineer wants and deserves an adequate salary that is commensurate with his contribution to the company and his professional position.

*Acceptance as part of the management team.* Engineers must be encouraged to understand that they have a stake in the company's profit or loss picture, its competitive position, and its future. They must be fully informed of management's goals, views, plans, and projects.

**Ethics.** This program requires constant vigilance for violations of the code of ethics that is observed by all major engineering societies. The NSPE's publication, *Ethics for Engineers*, has been placed in the hands of thousands of engineering seniors to serve as a guide to their actions and attitudes in their working career. The NSPE also participates in the formation of ethical standards for the profession and recommends means to attain and advance such standards. The Board of Ethical Review created by the NSPE is constantly concerned with interpreting specific circumstances in the light of the established Code of Ethics.

**Education.** The NSPE has contributed in the field of education through local and national programs designed, among other things, to improve the level of teaching of mathematics and the basic engineering sciences so as to effect continuing improvement in engineering education. The Society's programs in the educational field also cover the range from career guidance at the high school level to the administering of scholarships to high school seniors of proved ability. The local chapters have been most active in aiding the work of the Junior Engineering Technical Society (JETS) to enhance scientific, technical, and preengineering studies in the local schools. In addition, the NSPE is actively concerned with the development of courses in the engineering colleges and universities designed to foster professional concepts in the field of engineering.

**Continuing education.** In recognition of the vast field of new engineering knowledge, NSPE sponsors seminars and professional development courses. The Society also offers selected courses in programmed learning to the membership.

**Insurance and retirement.** Because of the purchasing power of the NSPE membership, the Society has been able to establish an outstanding package of insurance plans—term life, accidental death and dismemberment, long-term disability income, hospital expenses—at very reasonable rates. Further, there is a retirement program with guaranteed annuity through an insurance aspect and a variable annuity return via a mutual fund. The Society is currently investigating the possible availability of group automobile insurance.

**Other services.** Other benefits include an engineers' salary survey, conducted biennially and reporting results by age, field of employment, type of work, and degree of responsibility; subscriptions to *Professional Engineer*, *Legislative Bulletin*—a monthly report of legislation affecting engineering introduced into Congress, *Legislative Opinion Request*—a publication soliciting the opinions of the membership on various legislative proposals; and practice section newsletters for engineers in industry, government, private practice, and education.

Circumstances have brought about a greatly changed situation in engineering today. We realize that strong technical societies are a necessity; we have also come to realize that the profession must go beyond the purely technical realm—that it must be prepared to move outward toward a sincere and helpful public dialogue as to what can realistically be expected from technology in the years ahead.

**Harry C. Simrall** (F), president of the National Society of Professional Engineers, is dean of the College of Engineering, Mississippi State University. Active for many years in NSPE affairs, Mr. Simrall formerly served as Southeastern Regional Vice President and National Director for Mississippi. He holds degrees in electrical and mechanical engineering from Mississippi State University and a master's degree in electrical engineering from the University of Illinois. In 1968, he received the "Mississippi Engineering Leadership Award" from 11 engineering, technical, and professional societies in the state.

# Linear induction machines

## I. History and theory of operation

***For greater appreciation of the complexities of linear induction motors, Part I of this article not only examines the historical significance and theoretical aspects of such machines, but presents a comparison with conventional rotating motors***

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*The history of linear induction motors extends as far back as the 19th century. Although these machines have been practically forgotten for the last 30 or 40 years, there appears to be a genuine revival of interest in them. The fascinating history of these "unrolled" motors and their theory of operation is the subject of Part I of this article. Part II will deal with the unique advantages that such high-performance systems have for modern-day applications.*

The principle of the linear induction motor can be easily understood by analogy with the conventional rotating "squirrel-cage" induction motor.

Let us consider the motor of Fig. 1(A), which is made up of two parts. The stator is provided with windings so that circulating a set of balanced polyphase currents induces a sinusoidally distributed magnetic field in the air gap, rotating at the uniform speed $\omega/p$, with $\omega$ representing the network pulsation (related to the frequency $f$ by $\omega = 2\pi f$) and $p$ the number of pairs of poles. When the inner core rotates at a speed different from $\omega/p$, electromotive forces and currents are induced in the squirrel cage (rotor), and forces arising between the currents and the magnetic field drag the rotor in the direction of the field. It is important to understand that this principle would not be modified if the squirrel cage were replaced by a continuous sheet of conducting material, such as that represented in Fig. 1(B).

Now, if we imagine unrolling motor B, we obtain motor C of Fig. 1. Instead of a rotating flux, the primary windings now create a gliding flux. Furthermore, the magnetic core of the rotor may be separated from the conducting sheet itself and used only as a magnetic flux path. The secondary will then be moved by the primary field, which produces an electromotive force and currents. Naturally, when the secondary conductor is removed from the air gap, it has to be replaced; hence the secondary is drawn longer than the primary. This is called a "long-secondary" linear induction motor.

If $f$ is the network frequency and $\lambda$ the length of a pole pitch, the velocity of the mobile field is $\lambda f$ and is called "synchronous speed," replacing the angular synchronous speed $\omega/p$ of a rotating motor. It might also be wise to take advantage of the second stationary magnetic yoke and double the first windings, as indicated on Fig. 1(D). In addition, by making use of an infinite-length primary and a finite-length secondary, it is possible to obtain a one-sided short-secondary linear motor [Fig. 1(E)], or a double-sided short-secondary motor [Fig. 1(F)].

Other dispositions can be readily deduced from these configurations. For example, Fig. 2(A) represents a short primary with one part of the magnetic core facing a long secondary bound to the other part of the magnetic core. Figure 2(B) shows a long primary and a short secondary, each bound to a part of the magnetic circuit. In both cases, either part may be fixed with the other part moving. Motors patterned after Figs. 1(D) and 2(A) (i.e., short-primary motors) are the most widely used. Windings may be similar to those of the Gramme type, as the Urba motor [Fig. 3(A)] or the Aerotrain, or of rotating machines, like the first prototype built in Grenoble, France [Fig. 3 (B)].

Another form of linear induction motor is called "solenoidal," the principle of which is described by Fig. 4. A succession of solenoids, within which a current $i_1$ circulates, creates a magnetic field $b_1$ along the common axis that alternates direction. If $i_1$ is a sinusoidal function of time, $b_1$ will form approximately a sinusoidal standing wave representing the magnetic field along the $x$-axis. Now, if two other series of solenoids circulating currents $i_2$ and $i_3$ are interpolated between the first set (see Fig. 4), and if $i_1$, $i_2$, $i_3$ form a balanced three-phase system of frequency $f$, then the resulting axial flux will be approximately sinusoidally distributed along the $x$-axis, and will glide along this axis at speed $\lambda f$. A conducting cylinder laying along the $x$-axis inside the solenoids would experience a thrust in the direction of the moving field. Obviously, the better performances will be obtained if a magnetic circuit is provided (as in Fig. 5). It should be noted that the internal conducting cylinder is hollow and filled with iron, and that an external magnetic cylinder serves as a magnetic return path.

The principle of the solenoidal linear induction motor is sometimes explained in a very different fashion, as illustrated by Fig. 6. The primary of the conventional three-phase revolving field machine is thought of as being "unrolled" to lead to the inductor of the flat linear motor. This is again rolled, but in the other direction to form the primary of the cylindrical linear motor.

There still remains to be examined the motor type that Laithwaite has called "mock tubular." It will be more easily understood if one considers that section A of Fig. 5 can be considered as corresponding to either section B of Fig. 5 or the perspective of Fig. 7(A), where we see that the windings on the two external magnetic cores are so arranged that they create fluxes, along the motor,

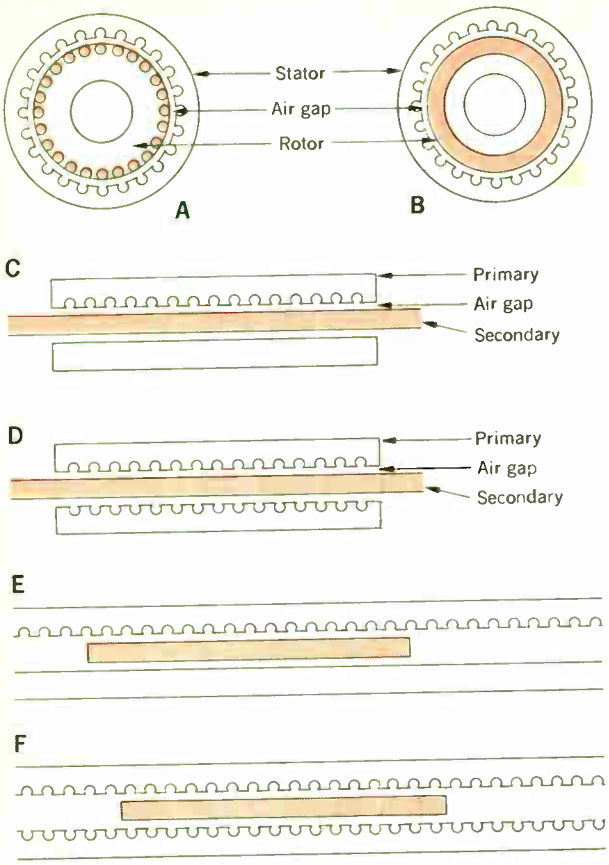
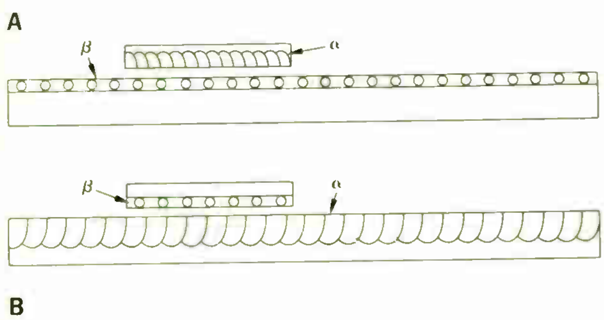



**FIGURE 1.** Transformation of the conventional squirrel-cage induction motor A into the less conventional drag cup motor B, then into the one-sided long-secondary linear motor with short-flux return yoke C, and finally the double-sided long-secondary linear motor D. Motor E has a one-sided short secondary with a long flux return yoke, and motor F a double-sided short secondary.

**FIGURE 2.** Examples of single-sided linear induction motors with a short primary (A) or a short secondary (B).




always in opposite directions [Fig. 7(B)], so that the flux lines must be closed through the inner magnetic core.

An obvious advantage of the linear motor is that it produces a translation motion directly. To obtain the same result with a conventional machine would require mechanical transformers such as screws, wheels, or cranks.

Another advantage, by far the most important for applications that first appeared, is that the thrust between primary and secondary is transmitted through a system of electromagnetic waves and, therefore, mechanical liaisons between the two parts are necessary only for guidance.

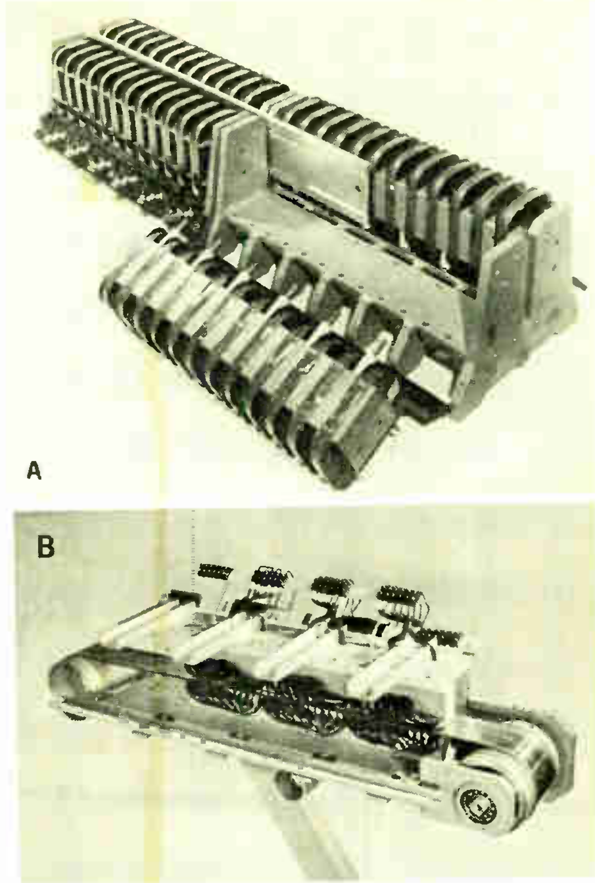
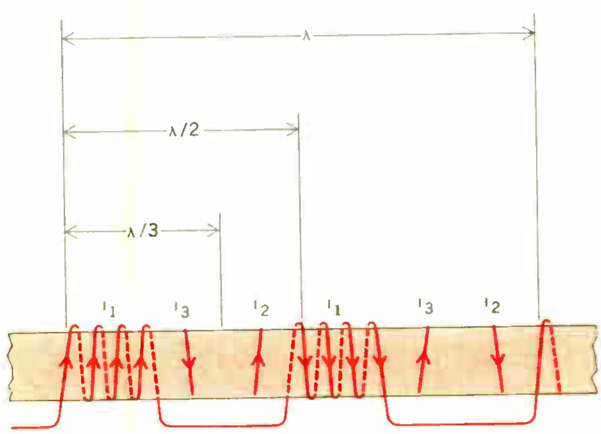


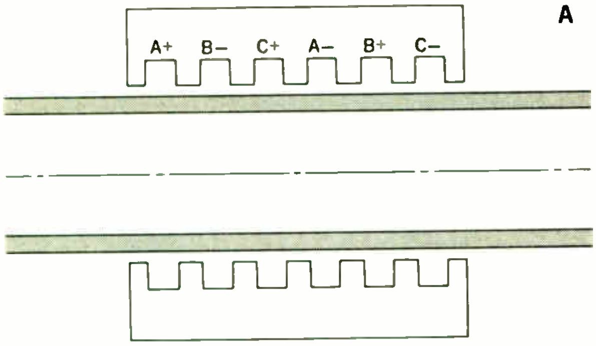

**FIGURE 3.** Primary windings may be of the Gramme type, as in the Urba motor (A), or the ordinary type (B), which was developed for laboratory experiments.

**FIGURE 4.** Engaging six sets of solenoids around a cylinder enables one to obtain a traveling sinusoidal wave of an axial field.

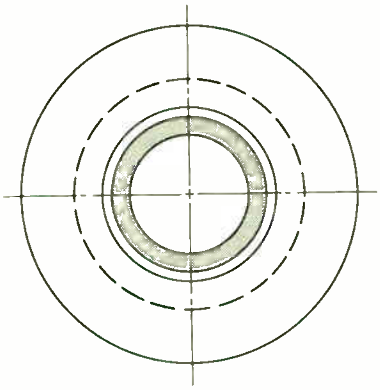



For example, if the primary of Fig. 2(B) is laid under the track of a railway, the secondary being bound under a train carriage, the so-called "coefficient of adhesion" (which is a term used by railway engineers, not quite identical to the "coefficient of friction" used in statics) of the wheels on the rail will be of no importance. The significance of this observation for railways is seen in the fact that not only acceleration but, more important, stopping distance, is limited by adhesion. Let us not for-

A




B



C

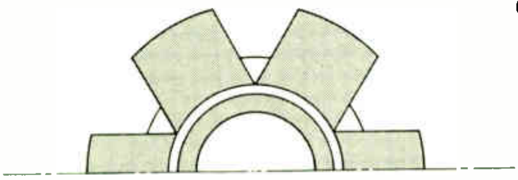
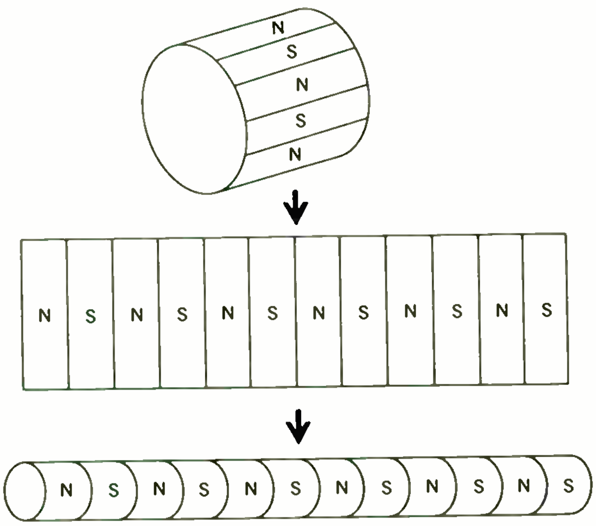


**FIGURE 5. Solenoidal (or cylindrical) linear induction motors have both external and internal magnetic cores, as in A and B. For simplicity of construction, the external yoke may be made as shown in the front view (C).**

**FIGURE 6. The primary of solenoidal traveling field motors may be thought of as the result of rerolling a flat linear motor, which is itself the result of unrolling a conventional rotating motor stator.**




get that passenger comfort is the factor that limits the rate of deceleration. (These points are discussed by F. T. Barwell in his paper, "Some Speculations on the Future of Railway Mechanical Engineering," *Proc. Inst. Mech. Eng.*, vol. 176, no. 3, pp. 61–83, 1962.)

As an additional example, if the secondary of the motor in Fig. 2(B) is bound to a weaving shuttle, it is possible to drive it by continuous action throughout its path across the loom, in spite of the warp threads and the reed.

These advantages explain why railroad electrification and shuttle propulsion were the first applications of linear induction motors, as revealed in the next section.

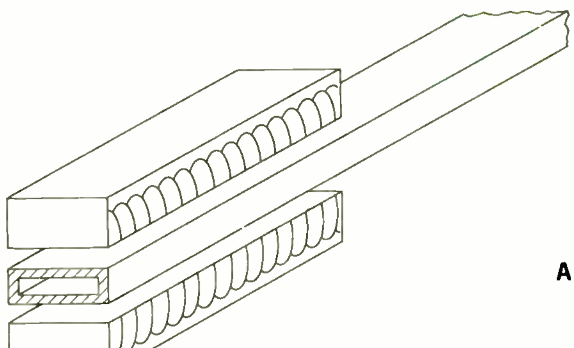
## History of linear induction machines

The idea of the linear induction motor is probably contemporary with the invention of the rotating-field machine by Tesla, Dolivo-Dobrovolsky, and Ferari sometime after 1885. However, some authors give other dates for the discovery. For instance, Chirgwin quotes a patent granted to Page[1] in 1851, but this was related to an oscillating motor driving a locomotive through the same system of cranks that was used in the steam locomotives of the day. Others cite as the real ancestor the electric shuttle developed by "the Weaver Jacquard and Electric Shuttle Company," who applied for a British patent in 1895.[2] The traveling field was poorly shaped, however, being created by a succession of independent electromagnets fed by a dc source through a mechanical inverter (see Fig. 8).

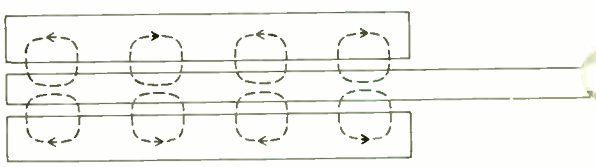
There is also the evidence[3] of the "Portelectric system," tried in Dorchester, Mass., around 1891 and intended for luggage transportation. The track went through solenoids, and a direct current switched on and off by the vehicle itself energized the solenoids, which "swallowed" at a well-chosen time the magnetic parts of the vehicle. As with the Jacquard motor, this was a synchronous machine, and again the shape of the traveling field was poor.

Similarly, we find a patent[4] relating to the use of "a

**FIGURE 7. The perspective shown in A may be considered to represent the cutaway view of Fig. 5(A). The two sets of windings create opposite magnetomotive forces everywhere, so that flux circulation is similar to that which is indicated on B.**



A



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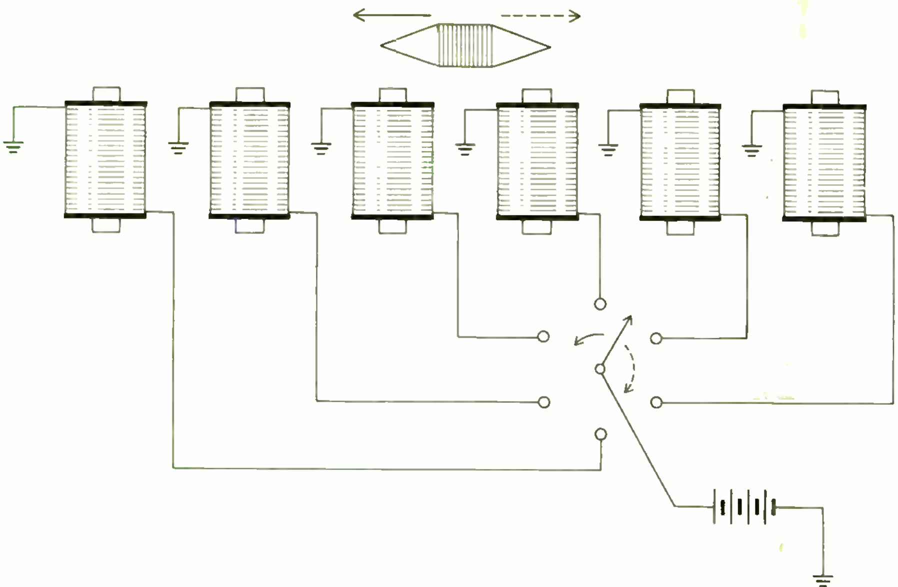


FIGURE 8. One ancestor of linear motors, the shuttle propeller of the "Weaver Jacquard and Electric Shuttle Company," was a synchronous motor fed through what would now be called a mechanical inverter.

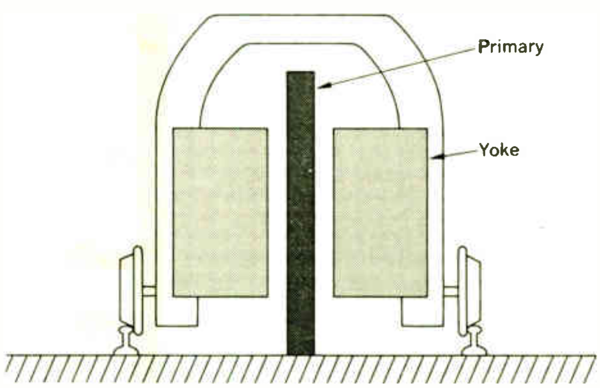
continuous succession of polar waves" for the propulsion of a vehicle over a railway (Fig. 9). The two-phase inductor was wound vertically all along the track, and the vehicle contained the magnetic circuit. Many parts of the patent are rather obscure, and the authors seem to have been thinking mainly of synchronous linear motors, although they do not mention starting problems and somewhere describe an insulated conductor wound around a magnetic piece.

It is said that a man by the name of Korda originated the idea of a train system that was reinvented by Rosenfeld, Zelenay, and Dulait, who actually experimented with it.[5-7] Beneath every car of the train was a secondary made of conducting material and a magnetic core. On the track were some primaries, with the distances between them less than the length of the secondaries so that it was always possible to start the train wherever it had been stopped. Wherever the slope of the track was steeper, the primaries were placed closer to each other to provide more power. The test track was electrified over a length of 400 meters and 20 primaries, 2.8 meters long, were Gramme-wound like those of Fig. 3(A). It is not possible to give all the interesting details described by the authors, but it is impressive to note that a reversal of field could be obtained from within the car (Korda had contemplated the possibility of braking the train by the use of a second track providing a reverse traveling field).

In 1902, Zehden[8] applied for a French patent on an "electric traction system" (he applied for a similar patent in the U.S. in 1907), in which he suggested dragging a train with a short primary mounted under the cars (or the locomotive), and using a long secondary with a configuration quite similar to those that are now tested for high-speed ground transportation (Fig. 10).

A natural application that also occurred at the beginning of the century was in the control of machine tools through linear motors.[9] After 1910, however, and until the end of World War II, the interest in linear machines drastically declined, with the exception of the electromagnetic gun[10,11] and various experiments on looms. At this time, the Westinghouse Electric Corporation began carrying out two large-scale experiments for the U.S. Navy.[12-15] The problem—aircraft launching—

FIGURE 9. Based on the principle of an invention by Wheeler and Bradley, a nonmagnetic two-phase primary extends along a track, with the yoke worn by the carriage being dragged by the moving field. Another type of linear induction motor could be obtained by the addition of a short-circuited secondary.




involved planes harnessed to a wheel-supported shuttle car supporting the primary winding. The secondary consisted of a developed squirrel cage, set flush with the ship deck. Its length was 425 meters, the useful core was 30 cm wide, and the required ac power amounted to 12 000 kW. The launching run was 300 meters long, and it lasted 4 to 15 minutes, bringing the plane from rest to a take-off speed that could be as high as 360 km/h. The accelerating force was constant during this period, since the secondary resistance was progressively decreased in four steps along the track by use of materials of different resistivity. After takeoff, the shuttle car was braked by a reversal of the magnetic field and stopped in the 125 remaining meters of track. Since the required power was 12 000 kW, 7000 amperes had to be collected through brushes and collector rails. Although its originators claimed that the launcher did not have the limitations in speed or capacity of the mechanical types of launching devices (as well as providing a much more comfortable acceleration rate), prohibitive expense prevented further development of the "Electropult."

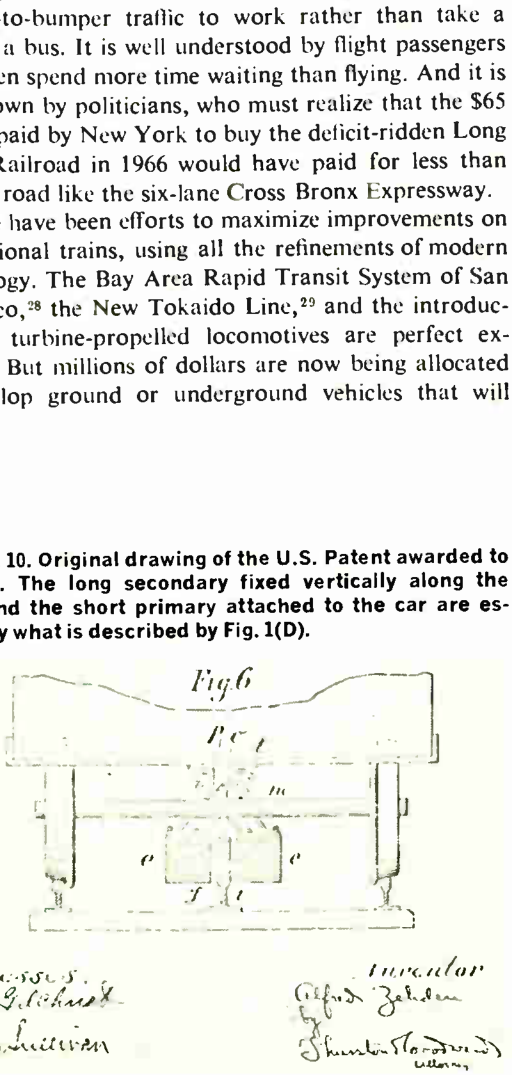
During this period, the development of nuclear energy led to the study of electromagnetic pumps for liquid metals, particularly sodium. Two types of pumps were similar to linear induction motors (the secondary conductor was just replaced by a conducting fluid)—the annular linear induction pump (Fig. 5) and the flat linear induction pump [Fig. 1(D)]. Furthermore, a search for new ways of generating electricity led to the investigation of "liquid-phase magnetohydrodynamic (MHD) generators." These include the liquid induction pumps just described, operating above synchronous speed.[16-20]

At about this same time, E. R. Laithwaite became interested in various "exotic" types of machines and became quite enthusiastic about the linear induction motor. He directed many theses on the subject in his laboratory at Manchester University, and the first results of his work were published in the *Proceedings of the IEE* (*London*).[21-26] Since then, he has written a quantity of papers in many professional journals, attracting the attention of many engineers to the subject. Investigators who had thought of using the linear induction motor for solving various problems, but had not really tried it, began to believe in its practicality.[27] For this very important work, Laithwaite was eventually named a Fellow of the IEEE.

The last development to bring attention to the linear induction motor arose from the need for better urban and intercity mass transportation. This need is well understood by those commuters who have to drive through bumper-to-bumper traffic to work rather than take a train or a bus. It is well understood by flight passengers who often spend more time waiting than flying. And it is well known by politicians, who must realize that the $65 million paid by New York to buy the deficit-ridden Long Island Railroad in 1966 would have paid for less than 5 km of road like the six-lane Cross Bronx Expressway.

There have been efforts to maximize improvements on conventional trains, using all the refinements of modern technology. The Bay Area Rapid Transit System of San Francisco,[28] the New Tokaido Line,[29] and the introduction of turbine-propelled locomotives are perfect examples. But millions of dollars are now being allocated to develop ground or underground vehicles that will travel at speeds so fast that wheels will be impracticable. The most extraordinary is a proposal by Edwards,[30] who contemplates vehicles traveling at speeds up to 800 km/h through dual evacuated tubes driven thousands of feet underground. At Rensselaer Polytechnic Institute in New York State, Foa[31,32] is studying reaction trains running through tubes at ground level. The greatest effort involving the linear motor for mass transportation, however, is based on the air-cushion principle, with vehicles employing this combination able to attain ultrahigh speeds. Reasons for this will be explained later.

**FIGURE 10. Original drawing of the U.S. Patent awarded to Zehden. The long secondary fixed vertically along the track and the short primary attached to the car are essentially what is described by Fig. 1(D).**




## A comparison of linear and rotating induction machines

From the description just given, one could easily conclude that, at least theoretically, the problems encountered with linear induction motors are not any more complex than those of rotating motors. This, of course, would be an erroneous assumption, mainly for these reasons: (1) the inherent dissymmetry of primary currents; (2) the end effect; (3) the great length of air gap.

The dissymmetry of primary currents is illustrated by Fig. 11. It can be seen that many flux lines travel from one magnetic core to the other outside of the air gap. This of course implies that the inductance of a coil is a function of its position along the air gap, the opposite of what is found in a rotating machine. The connection of the windings to a three-phase balanced power network will therefore result in the flow of nonbalanced three-phase currents. Hence, the primary magnetic field in the air gap can be divided into three components—two sinusoidal traveling waves (one forward and one backward), and a stationary wave of constant amplitude. The action of the traveling waves is familiar; the stationary field acts as a brake (Fig. 12).

The end effect is simple to understand, as can be seen from Fig. 13. Let us consider a secondary sheet, the relative speed of which, with respect to the primary, is $V$. At a given time, a point $M$ of the sheet is in $M_1$, with the small circuit $C$ surrounding $M$ not linked to any flux. Later, as $M$ enters the air gap and is in $M_2$, the flux through $C$ may vary abruptly, thus inducing a current according to the law of constant linkage. This current will be superimposed upon the currents that are induced in the equivalent rotating machine, and results in the "entry effect." Its decrease with time will depend on a time constant $T$; theoretically, it should still exist when $M$ is in $M_3$. Finally, an analogous phenomenon, the "exit effect," takes place when $M$ travels out of the air gap through $M_4$.

It should be noted that, even if the field appears as a perfect traveling wave $b = b_m \cos(\omega t - \nu x)$, and the secondary is moving at the synchronous speed $\omega/\nu$, the end effect still exists and gives rise to Joule losses, opposing a braking force to the relative motion and preventing the motor from ever attaining synchronous speed. For a given magnetic traveling field, the total thrust due to end effect varies with slip, and may be positive or negative in the interval $0 < S < 1$, with several changes of sign.

The importance of such parasitic thrusts varies widely. If $T$ is small as compared with the traveling time of the point $M$ along the air gap, they are negligible. The shape of the fringes, that is to say, of the curve $B(x)$ outside the air gap just before entry and just after exit, is also very important. Indeed, it is felt that, if $B(x)$ is a step

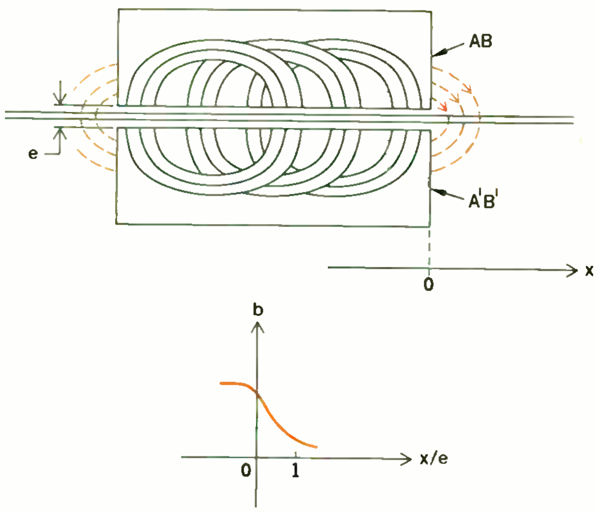



**FIGURE 11.** A—At the two extremities of the magnetic circuits, lines of flux travel outside of the air gap; therefore, the various phase cells do not have the same self-inductance. Shielding surfaces AB and A'B' with a conducting sheet would be inefficient to hinder the parasitic flux. B—The induction magnetic field, which decreases slowly from inside to outside of the air gap, is shown as a function of x/e.

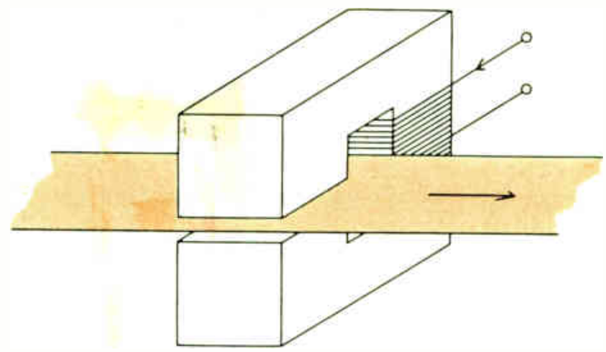
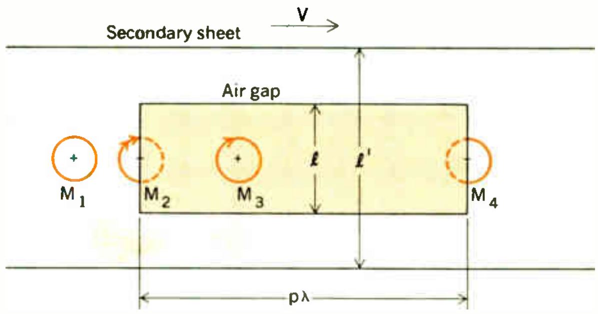


**FIGURE 12.** The constant-amplitude stationary field in the air gap of an induction motor has a braking effect on the secondary, exactly as that produced by the field of this alternating-current-fed electromagnet.

**FIGURE 13.** An explanation of the end effect.




function, the parasitic EMF will be greater at the entry and exit than if the variation is smooth, as indicated by Fig. 11. In addition, the ratios $L/l$ and $l/p\lambda$ must be considered. Recently, works have been published that corroborate these ideas.[33-35]

In linear induction machines, the length of the air gap is necessarily greater, for mechanical reasons, than in rotating ones. This is true for motors of the kinds described by Fig. 2, where the secondary conductors can be embedded in magnetic material; and it is even more true for motors of the kind described by Fig. 1(D), where lines of forces are made longer by the presence of the nonmagnetic secondary. Inspection of photographs that are related to the Aerotrain or to the Garrett experiment[36] shows that air gap is sometimes made even longer by use of a hollow secondary. It is a fact that, under these conditions, the magnetizing power has to be high, in which case, the power factor will be poor. Therefore, either the primary Joule losses or the primary copper volume will increase, as in the case of rotating machines [Fig. 1(B)] that are built for very special purposes.

All these inconveniences, which are more or less dependent on each other, may be partly overcome by various means. For example, one would imagine that, by shielding sides $AB$ and $A'B'$ (Fig. 11) with a conducting screen, it would be possible to contain the parasitic flux of magnetic induction. Experience, however, has shown that this solution is very inefficient. Actually, reduction of end effects has been obtained by pump and MHD generator designers by either grading the windings or using compensating windings.[16-20]

At any rate, for most applications, reasonably good results can be achieved without any compensation of the parasitic effects. Oddly enough, this result was believed to be impossible by many experts who had not tested its validity. In particular, says Chirgwin,[37] "it is interesting to note that a famous electrical engineer, Charles Proteus Steinmetz, is quoted as saying in 1922 that a linear induction motor was not practical for traction applications on account of its end effects."

After having determined the important differences that exist between linear and rotating motors from a theoretical point of view, let us try to ascertain what differences exist from a purely practical vantage point.

1. The motors described by Figs. 2(A) and 2(B) seem to suffer from a large attractive force (up to ten times the thrust) between the moving and stationary members. However, Ooi and White recently published a paper[38] in which they consider that, under certain conditions, this attractive force could vanish and even become negative, so that sustentation would be obtained at the same time as thrust. It should be noted that motors described by Figs. 1(D) and 9 do not suffer from this attraction; however, a force is exerted between the two parts of the magnetic circuit.

2. Absence of wearing parts such as gears is an advantage, but, since thrust is determined by motor size, in low-speed application there is no possibility of gearing down a small motor to produce large thrusts.

3. Speed is not limited, since there are no centrifugal forces.

4. Generally, all types of linear motors are easy to cool because of their construction; moreover, if the secondary is long, then each part of it is warmed during only a fraction of time. This is very important because, in most cases, high efficiency is obtained, not on the basis of energy cost, but from thermal considerations. This may compensate for the increased size of the air gap.[39]

## Theory of operation

A linear induction motor is schematically represented by Fig. 14, where the symbols that we shall use in this section have been defined. For our purposes, iron permeability may be assumed infinite. The slots represented contain three sets of windings, which are connected to a regular three-phase balanced power supply. From factors already considered, we know that the currents are not balanced, since a set of balanced three-phase currents does not produce a gliding field. Therefore, we shall employ the superposition theorem and study separately the currents and forces produced by the primary fields; namely, the forward and backward gliding fields and the stationary field. For the sake of simplicity, we shall limit ourselves to the study of the forward gliding field and assume that the magnetic end effect is negligible for the induced current. We shall particularly delve into the main features of the lines of currents in the secondary, as well as the nature of the mathematical methods.

To start, let the primary field be

$$b_p = b_{pm} \sin(\omega t - \nu x + \theta)$$

where $\omega$ is the network pulsation ($2\pi \times$ frequency), $\nu$ takes into account the pole pitch, and $\theta$ is a phase angle.

From this, we must find the currents in the copper sheet when its speed, relative to the primary, is $V$. The unknowns will be the components of the current density along the $x$- and $y$-axis, $j_x(x,y,t)$ and $j_y(x,y,t)$, together with the induction density that they produce, $B_s(x,y,t)$. These are all related, along with the data, by the expressions of three fundamental laws: Ohm's law, Ampere's theorem, and the conservation of current.

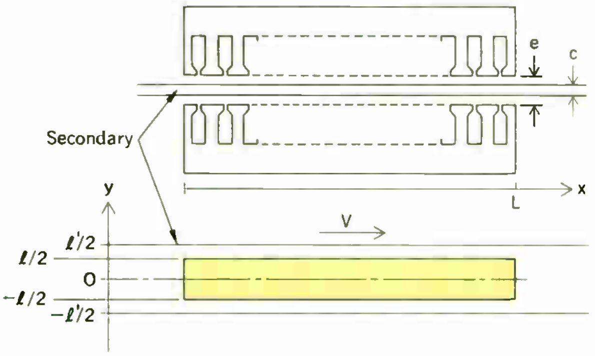
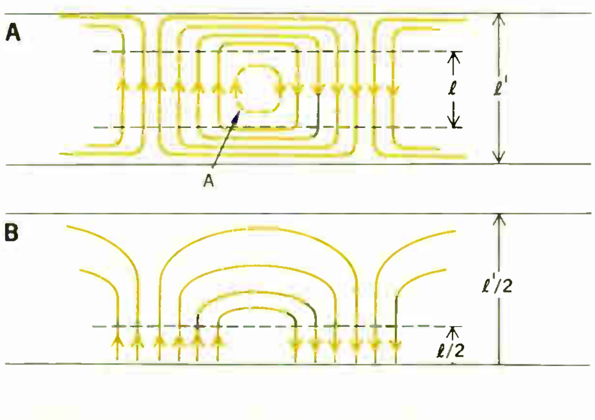



**FIGURE 14. Example of a schematic representation of the linear induction motor.**

**FIGURE 15. The general shape of lines of current.**




Mathematically, there seems to be no problem. Unhappily, if extremity effect is taken into account, no solution can be handled without an extreme amount of programming. Since, at the beginning of our study, we needed to have a set of equations that were simple enough but at same time not too misleading, we began an interest in the following case: If $l'$ is larger than $l$ (Fig. 14), without being too large, then the lines of current will be approximately parallel to $0x$ ($j_y \neq 0$) when $+ l/2 < |y| \leqslant l'/2$, and parallel to $0y$ ($j_x \neq 0$) when $|y| \leqslant l/2$.[40-42]

It is easy to see that such a hypothesis may be valid only in a narrow domain, but it necessarily corresponds to a well-designed motor, as displayed in Fig. 15(A). Indeed, most of the forces exerted by the induction field on line A are inefficient, although all the forces exerted on the other lines of current are useful, since they are directed in the direction of motion. Therefore, in the two cases represented in Fig. 15, all the magnetic induction is well used. However, if $l'$ is too large [Fig. 15(B)], only a few lines of current will reach the edge of the secondary, and conductor utilization will be poor. Naturally, for given $l$ and $L$, it is not easy to find the best value of $l'$; it should be emphasized that the greatest difficulty in such a study is the construction of a mathematical model, rather than the mathematical treatment itself. In this particular case, we may be helped by a classic paper written by Trickey[43] or by a conducting-paper analog.

The considerations just outlined allow us to reduce the problem to a single dimension. Let us define

$j(x,t)$ = current density $j_y(x,t)$ for $|y| \leqslant l/2$ (in A/m²)
$b_i(x,t)$ = secondary induction (in teslas)
$J(x,t)$ = "return current" (defined in Fig. 16) (in amperes)
$\sigma = 0.5c(l' - l)$ = section of the return paths

Hence, the fundamental laws are defined as (within the air gap $0 \leqslant x \leqslant L$):

$$\frac{\partial j}{\partial x} + \frac{2}{\sigma l} J = \frac{1}{\rho}\left(\frac{\partial}{\partial t} + V\frac{\partial}{\partial x}\right)(b_i + b_s) \quad \text{(Ohm's law)}$$

$$-\frac{\partial J}{\partial x} = cj \quad \text{(current conservation)}$$

$$\frac{\partial b_i}{\partial x} = \frac{c\mu_0}{e} j \quad \text{(Ampere's theorem)}$$

Outside of the air gap ($x < 0$ or $x > L$), the flux density is identically zero, and we get

$$\frac{\partial j}{\partial x} + \frac{2}{\sigma l} J = 0 \qquad -\frac{\partial J}{\partial x} = cj$$

In all, there are seven limiting conditions:

The total flux through the air gap must be zero.

The current densities $j(-\infty,t)$ and $j(\infty,t)$ must be zero.

The current $J$ must be continuous at $x = 0$ and $x = L$.

Discontinuity of the magnetic field for $x = 0$ and $x = L$ corresponds to a discontinuity of current density at these points. This phenomenon constitutes the "extremity effect," which was physically described previously and which now appears in the equations. Notice that, if $b$ is the total induction, the relation

$$\frac{\partial j}{\partial x} + \frac{2}{\sigma l} J = \frac{1}{\rho}\left(\frac{\partial b}{\partial t} + V\frac{\partial b}{\partial x}\right)$$

contains only two terms that can be infinite: $\partial b/\partial x$ and $\partial j/\partial x$, so that

$$\frac{\partial j}{\partial x} \neq \frac{V}{\rho}\frac{\partial b}{\partial x}$$

Integrating in the interval $(-\epsilon, +\epsilon)$ and letting $\delta j_i$ and $\delta b_i$ be the abrupt variation of $j$ and $b$ for $x = 0$, we get

$$\delta j_i = \frac{V}{\rho}\,\delta b_i$$

for the entry. Similarly,

$$\delta j_0 = \frac{V}{\rho}\,\delta b_0$$

at the exit ($x = L$).

Now, if we are interested only in the steady state, with $V$ a constant, we can replace the real functions of $x$ and $t$, or $j$, $J$, $b_s$, and $b_t$, by the following complex functions of $x$ only: $\mathbf{j}$, $\mathbf{J}$, $\mathbf{b}_s$, $\mathbf{b}_t$.

The new equations within the air gap then become

$$\frac{d\mathbf{j}}{dx} + \frac{2}{\sigma l}\mathbf{J} = \frac{V}{\rho}\left(j\omega + \frac{d}{dx}\right)(\mathbf{b}_i + \mathbf{b}_s)$$

$$\frac{-d\mathbf{J}}{dx} = c\mathbf{j} \qquad \frac{d\mathbf{b}_i}{dx} = \frac{c\mu_0}{e}\mathbf{j}$$

It is now a simple matter to arrive at

$$\frac{d^3\mathbf{b}_i}{dx^3} - \frac{V\mu_0 c}{\rho e}\frac{d^2\mathbf{b}_i}{dx^2} - \left(\frac{2c}{\sigma l} + j\omega\frac{c\mu_0}{\rho e}\right)\frac{d\mathbf{b}_i}{dx} = \frac{\mu_0 c}{\rho e}\left[V\frac{d^2\mathbf{b}_s}{dx^2} + j\omega\frac{d\mathbf{b}_s}{dx}\right]$$

Hence, $b_i(x)$ is dependent upon three constants within the boundaries $0 \leqslant x \leqslant L$. Furthermore, these equations imply that the currents for $x > L$ depend on two constants, as is the case for $x < 0$. Therefore, it is seen that a total of seven constants are derived from the seven limiting conditions just stated. Further details regarding this may be obtained from Refs. 40–42. It should be noted that, if the width of the motor is assumed infinite, these results reduce to those cited by Nix and Laithwaite,[44] who characterized them by a second-order differential equation.

A complete study of the shape of the lines of current (Fig. 17) has been given by Sabonnadière,[45] who has also formulated an equivalent circuit that is most helpful in understanding the validity of the simplified theory.[46]

One point that may stimulate discussion involves the expression of the extremity effect. As a matter of clarification, it must be realized that infinite derivatives of the induction $\partial b/\partial x$ have been assumed at the entry and exit edges, resulting in only an approximation. The actual value of this approximation is developed in Refs. 33–35.

We have attempted to present an outline of the simplified theory of linear induction machines, as well as a brief history of their development. Although still less than perfect, the knowledge gained has greatly helped the author and his associates in designing the medium-size motors that were required for the Aerotrain Suburbain and the Urba systems. In particular, it has been extremely helpful to be able to analyze the extremity effect with better accuracy than that allowed by previous methods. It is hoped that the specific references cited while describing the wide range of problems associated with these complex

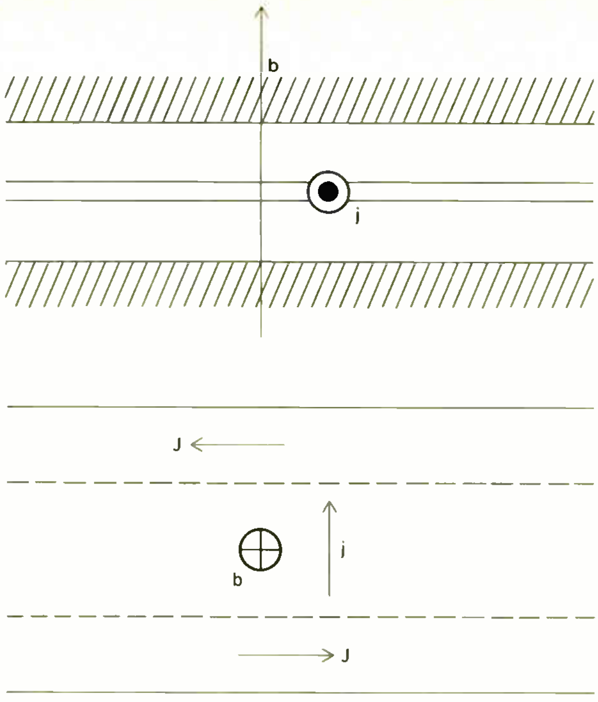
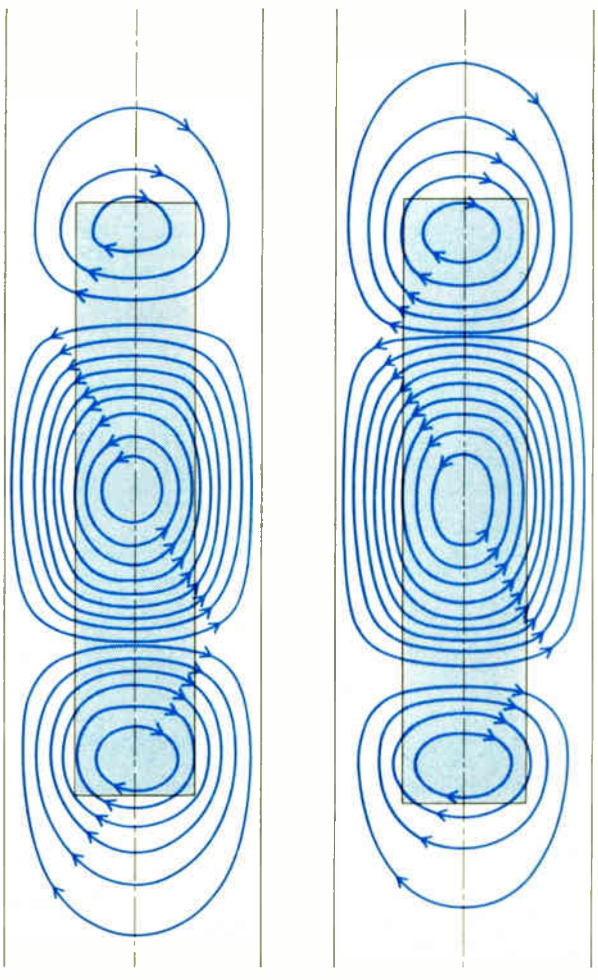



**FIGURE 16. Representation of terminology used in the mathematical analysis of linear induction motors.**

**FIGURE 17. Exact shape of lines of current as computed by Sabonnadière using a numerical method.**



machines will provide the necessary detail for those readers who desire a more rigorous and thorough examination of specific areas. (See also Ref. 47.)

The reader is invited to follow up this introduction to linear induction machines by reading Part II of this article, scheduled for the next issue of *IEEE Spectrum*, which will describe specific applications that are being developed to utilize these unique systems.

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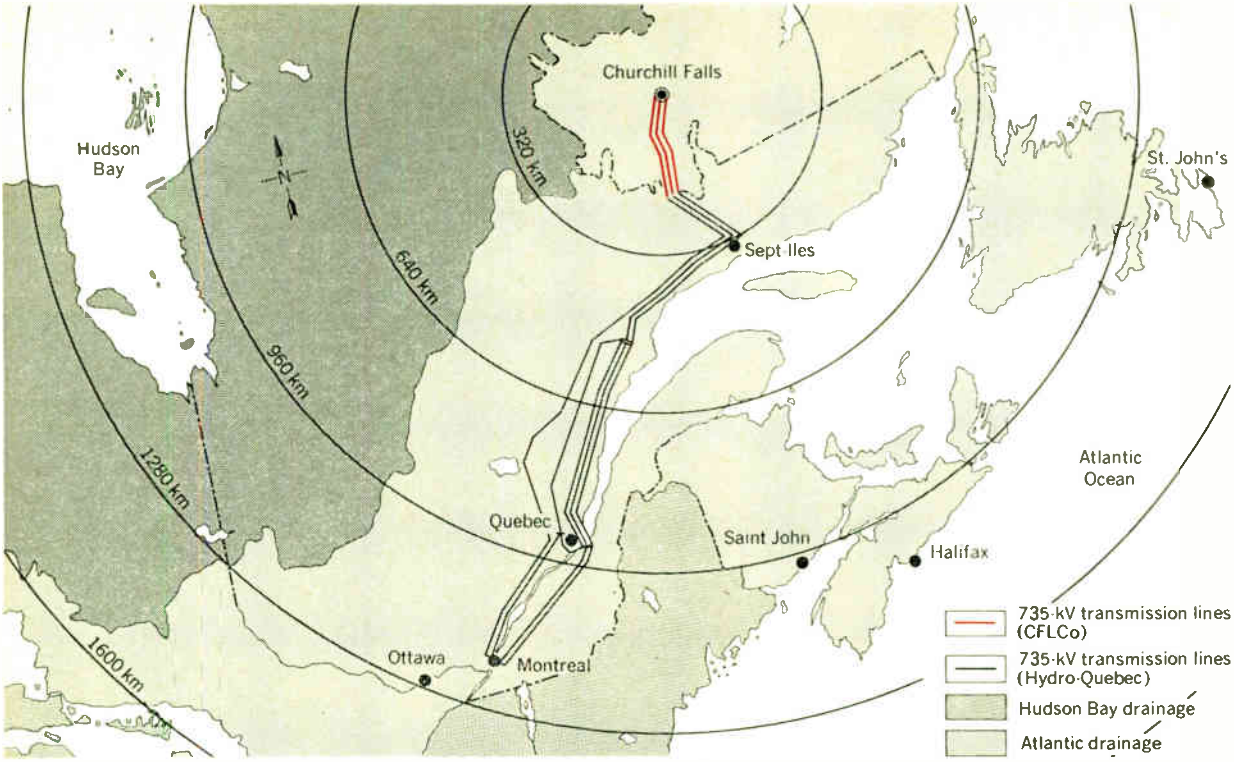
**Michel Poloujadoff** (M), born in Asnières, France, is ingénieur diplomé de l'Ecole Supérieure d'Electricité (Paris), master of sciences (Harvard), and docteur ès sciences physiques (Paris). After the completion of his military service, he joined the Institut Polytechnique de Grenoble, where he has been primarily engaged in teaching the theory of electric machines and lines. Dr. Poloujadoff's research activity has been oriented mainly toward the theory of induction machines and linear induction motors. In 1964, he founded a research group, along with Y. Pelenc and E. Remy, two associates from the Merlin et Gerin Company of Grenoble, to investigate the theory and application of linear induction motors. This group has been responsible for some of the first major contributions in this field to appear in continental Europe. Dr. Poloujadoff is a membre lauréat of the Société Française des Electriciens, and has published extensively in the literature.




**MAP OF northeastern Canada showing the Churchill Falls site, the EHV transmission network, and the drainage areas.**

# Power from Labrador: the Churchill Falls development

***One of the world's largest hydropower projects has passed the halfway mark toward completion. It will provide large blocks of firm power to commerce and industry, over an EHV network, as far as Montreal, more than 1100 kilometers distant***

**Gordon D. Friedlander** **Senior Staff Writer**

*The Labrador Plateau of northeastern Canada, which is more than 460 meters above sea level, forms a shallow "saucer"—with a few chips missing in the rim. Thus some water escapes through these low points to other streams; but most of the drainage is through the Churchill River, whose most dramatic feature is the 75-meter-high Churchill Falls. Long reaches of rapids precede and follow the falls so that the river drops more than 300 meters over a course of 30 km through a deep cut in the edge of the plateau. By means of man-made diversions, the water that would normally cascade over the rapids and falls will be retained on the plateau and directed into a new channel leading to the forebay intake of the power plant. The dents in the saucer will be "plugged" by 64 km of low dikes. The impounded water will back up to fill a reservoir area that will be about 40 percent of the area of Lake Ontario.*

*At a newly constructed outlet, the water will funnel down 11 penstocks to a huge underground powerhouse, through 11 turbines, each driving a generator; thence it will flow into a surge chamber, follow two tailrace tunnels, and emerge finally into the Lower Churchill River. An unusual feature of the huge powerhouse complex will be a central computer capable of monitoring hundreds of plant functions. Under normal circumstances, two operators in the central control room will be sufficient for station operation.*

*The reader should be aware that any hydro project—and especially one of such magnitude as Churchill Falls—is an interdisciplinary collaboration of structural, mechanical, and electrical engineering.*

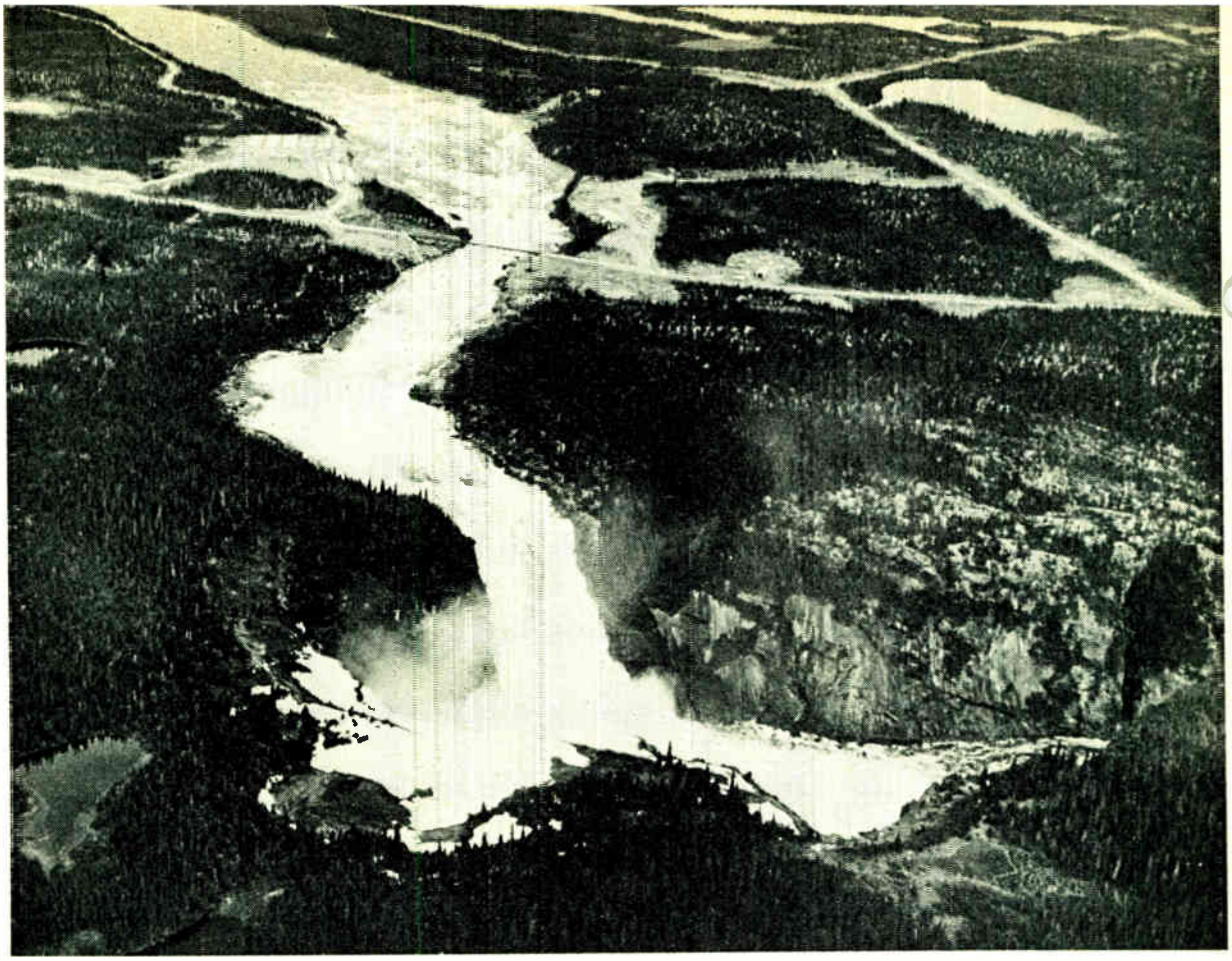


FIGURE 1. View of Churchill Falls, the high cataract of the Churchill River, for which the vast development is named.

The natural sites for feasible large-scale hydropower development are very limited, but we are today witnessing in Labrador the latter stages of one of the world's most ambitious projects in that category. Its statistics alone—in ultimate generating capacity, volume of excavation and tunneling, and construction of ancillary appurtenances—are enough to boggle the mind.

## Historical background

In August 1839, John McLean, a veteran Scottish trader for the Hudson's Bay Company, became the first white man to view what is now Churchill Falls in central Labrador. In his *Notes of 25 Years' Service in the Hudson's Bay Territory*, McLean said his party was still some distance away "when, one evening, the roar of a mighty cataract burst upon our ears, warning us that danger was at hand..."

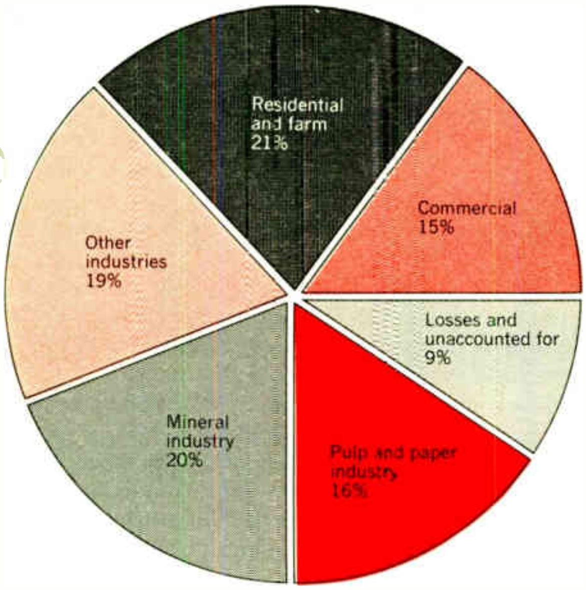
From a width of several hundred yards, he wrote, "the river...rushing along in a continuous foaming rapid, finally contracts to a breadth of about fifty yards, ere it precipitates itself over the rock which forms the fall. It continues its course for a distance of thirty miles, pent up between walls of rock that rise sometimes to a height of three hundred feet on either side...This stupendous falls (Fig. 1) exceeds in height the Falls of Niagara."

He concludes the description by the observation: "Such is the extraordinary force with which it tumbles into the abyss underneath, that we felt the solid rock shake under our feet as we stood two hundred feet above the gulf..."

**Recent events; power requirements.** It was not until 1953, however, that systematic studies of the potential

FIGURE 2. The Twin Falls hydro plant on the Unknown River, a tributary of the Churchill. This facility, with a capacity of 224 MW, was built in the 1960s to supply power to the mining industries in the Wabush area.

Principal uses of electric energy in Canada*




*From the Federal Department of Energy, Mines and Resources

**FIGURE 3. "Pie" chart showing the percentages of the principal uses of electric energy in Canada.**

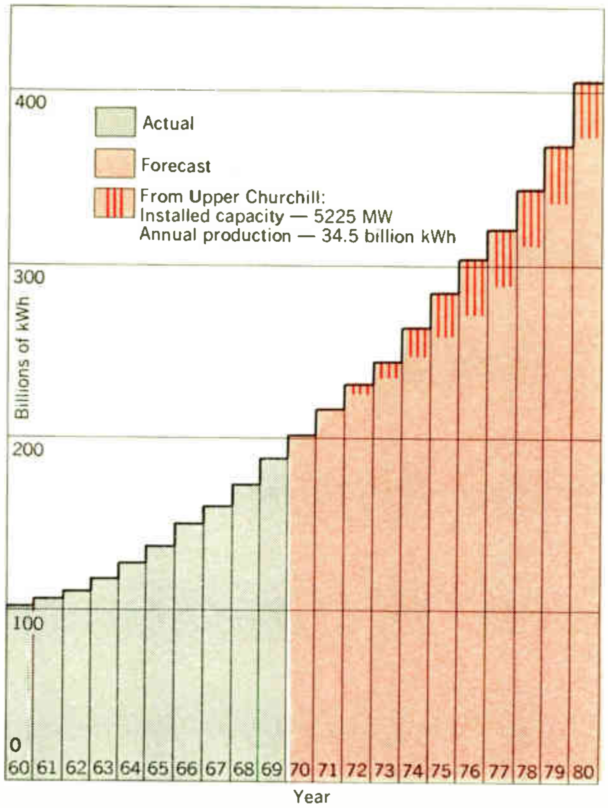



**FIGURE 4. Graph of present and forecast firm energy requirements within Canada.**

power site were initiated by the newly formed British Newfoundland Corporation Ltd. (Brinco), which was formed to explore and develop the natural resources of Newfoundland and Labrador. In 1954, the Quebec North Shore & Labrador Railway was built to serve the mining interests in the Labrador Trough; thus it was possible to build an economical access, over a distance of some 190 km, from the railway to the proposed development area.

Extensive geological explorations and engineering studies were conducted during the next two years (1954–1956) and, in the early 1960s, the 224-MW Twin Falls hydro plant was built on the Unknown River (see Fig. 2 and area map, Fig. 6), a tributary of the Churchill, to supply power to the mining industries in the Wabush area. This initial development, with its roads, airfields, camps, etc., was a key factor in advancing the Churchill Falls project.

The Canadian demand for electric power, similar to that of the United States, is doubling every decade. The Fig. 3 "pie" chart shows the percentages of the principal uses of electric energy throughout the Dominion; and Fig. 4 graphically illustrates the Canadian power growth phenomenon, including the future contribution of the Churchill Falls development. In view of this soaring energy requirement, a detailed report, completed in 1964, established the economic advantages and technical feasibility of the full development of Churchill Falls.

In 1965, the successful operation by the Hydro-Electric Power Commission of Quebec (Hydro-Quebec) of its 735-kV ac system (linking the Manicouagan generating complex with the load center at Montreal), further validated the practicality of EHV transmission from Churchill Falls to distant areas. With a generating capacity of 5225 MW by the mid-1970s, the Churchill plant will have an annual production equal to 20 percent of Canada's total power requirement in 1968.

To fulfill its commitment at Churchill Falls, Brinco formed the Churchill Falls (Labrador) Corporation Limited (CFLCo). By doing this, the provincial jurisdiction over the resource was allied with private shareholders, resource development corporations, and the principal purchaser of its electric energy, Hydro-Quebec.

In 1964, H. G. Acres & Company Limited and Canadian Bechtel Limited formed a joint venture called Acres Canadian Bechtel of Churchill Falls (ACB) to provide engineering and construction management services to CFLCo. Preliminary engineering studies for the Churchill Falls project began in 1966, and detailed design was initiated in 1967. Negotiations for a long-term power agreement between CFLCo and Hydro-Quebec resulted in the signature of a letter of intent between the two parties in 1966, and a formal contract for the purchase of most of the energy to be produced at Churchill Falls was consummated in 1969. The construction at the power site commenced in 1967.

**Management control.** CFLCo is responsible for the overall project management of the entire development scheme and ACB is the prime engineering and construction management unit for the project. In operation, plans are prepared by ACB and other design firms for CFLCo review and approval, and the execution of plans is carried out under ACB management.

## The master plan

The project site is about 1100 km northeast of Montreal, and 240 km west of Goose Bay, Labrador. All new facilities either planned or already constructed by

CFLCo are within a 200-km radius of the power station site.

**Catchment areas and "channel scheme."** The principal reservoirs (see Fig. 5 map) lie within the catchment area of the Upper Churchill Basin. Within this 70000-km² region are the Main Reservoir—consisting of Sandgirt, Lobstick, Michikamau, and Orma Lakes (Fig. 6)—which is being created on the Labrador Plateau to regulate the flow of the Churchill River and the Ossokmanuan Reservoir. Actually, the Ossokmanuan has already been developed to control flow to the existing Twin Falls Power Plant. Later construction will permit discharge into the Main Reservoir through the Gabbro Control Structure (Fig. 6). Referring again to the Fig. 6 map, one will note that the flooded areas of the Main and Ossokmanuan Reservoirs—together covering 6540 km²—and the forebay to the powerhouse will be enclosed by 64 km of low-level dikes and six control and spillway structures (Figs. 7 and 8). The 31 billion cubic meters of usable storage impounded in these semiartificial lakes will be replenished by an average of 76.5 cm of annual precipitation over the Upper Basin. And these reservoirs will provide a controlled flow of 1370 m³/s.

In the "channel scheme," the discharge regulated by the Lobstick Control Structure will flow down the Upper Churchill River channel for about 56 km, where it will be diverted—26 km east of the Falls—to the forebay intake (Figs. 9 and 10) by dikes flanking the Jacopie Spillway. By this means, a new channel, carrying the entire river flow, will be established along the rim of the vast plateau. The Whitefish Falls Control Structure will finally divide the channel toward the intake in an east and a west forebay to control the formation and drift of seasonal ice cover.

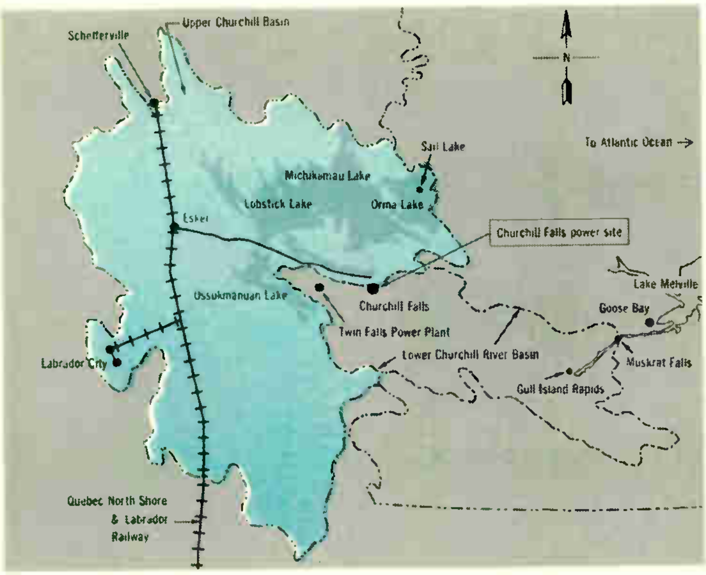
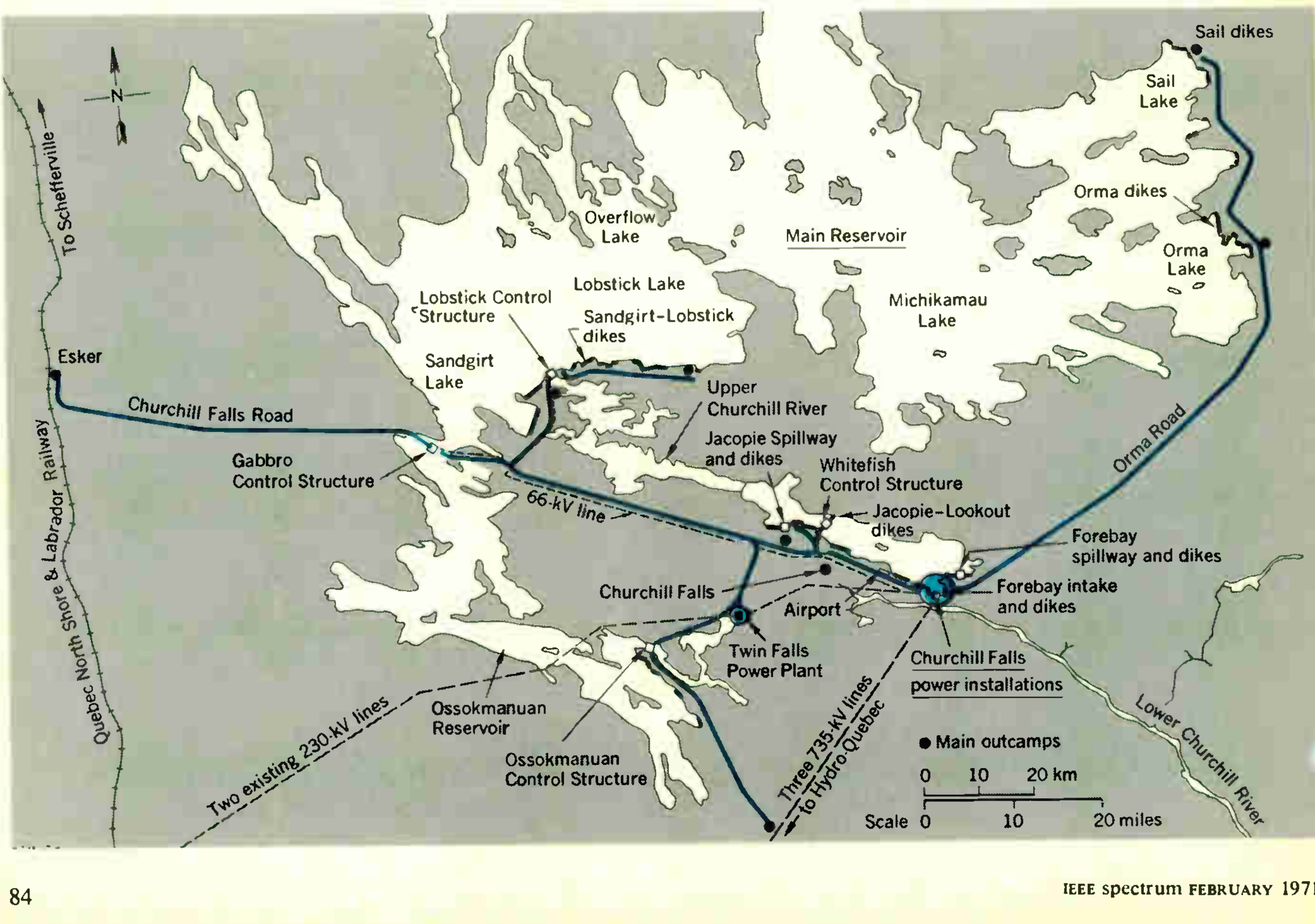



**FIGURE 5. Map of the principal reservoirs lying within the catchment area of the Upper Churchill Basin.**

**FIGURE 6. Map of the entire Churchill Falls development area. Within this 70 000 km² region are the principal reservoirs and construction appurtenances of the project.**



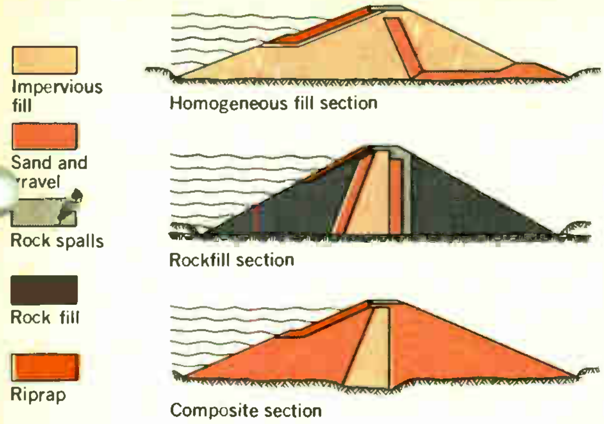



**FIGURE 7. Cross sections of the three basic dike designs, all of which contain riprap protection against wave action. Homogeneous dikes are the most common and are mainly built of compacted glacial till. Rockfill dikes are used when broken rock is available from nearby excavations. Composite dikes contain mainly sand and gravel fill.**

**FIGURE 8. Aerial view of typical reservoir control structure of the Churchill Falls development.**

**FIGURE 9. Enlarged map of the power plant area, principal transmission lines, upper and lower rivers, permanent townsite, etc.**

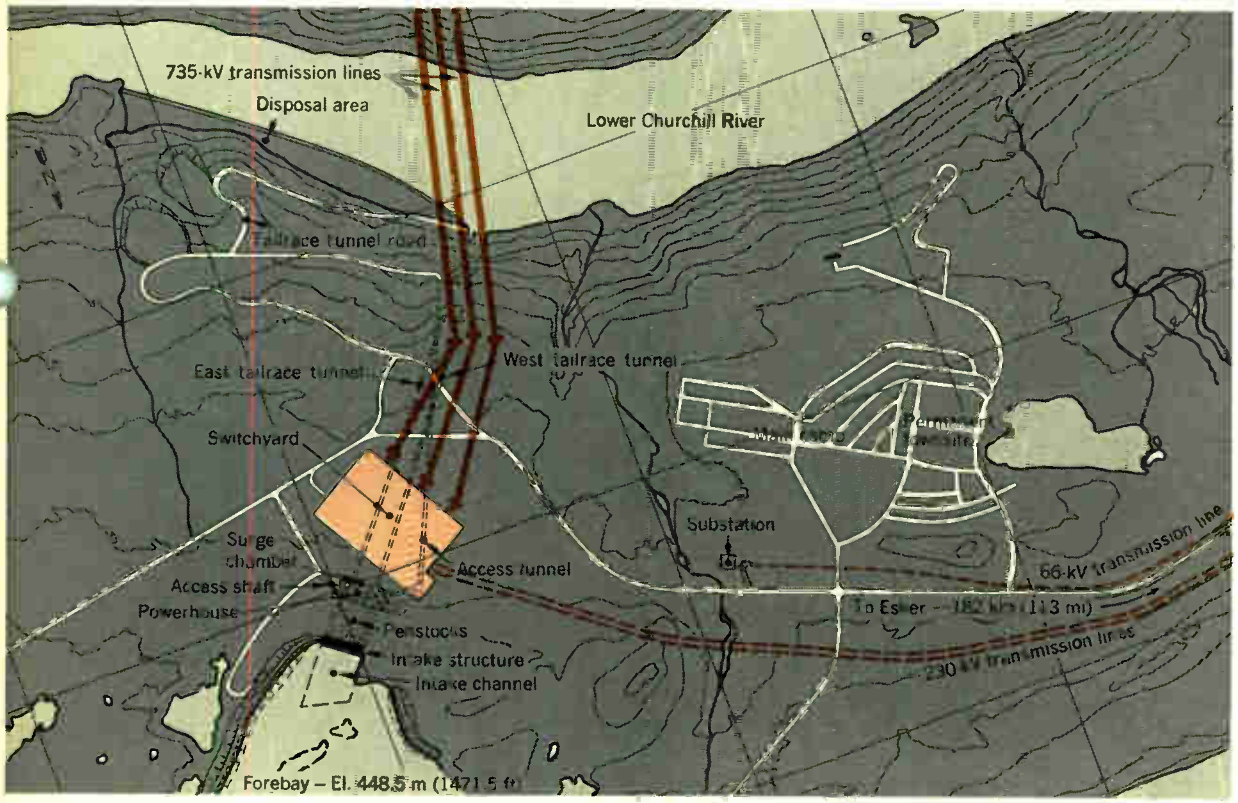
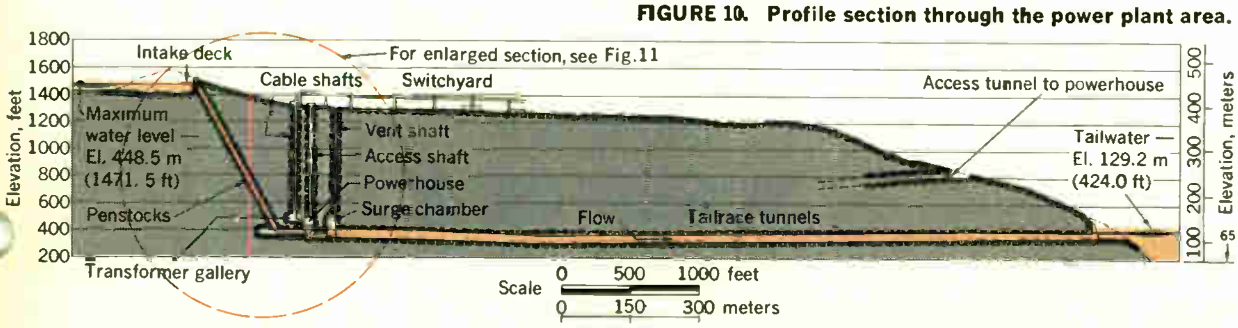



**FIGURE 10. Profile section through the power plant area.**



**Power plant capability.** The gross head made available by the channel scheme will be 324 meters, but allowing for frictional losses, the net head will be about 318 meters, at normal plant load. Because of the large volume of the storage reservoirs, the engineering estimates predict that 98 percent of the total flow available from the drainage basin will be used for power production. The nameplate capacity (as already mentioned) will be 5225 MW, at 313 meters net head, when all 11 generating units are running, and the average annual energy production will be about 34.5 billion kWh.

Figure 11 is an enlarged and detailed view of the power-plant structures that lie within the circle indicated in the Fig. 10 profile. The Fig. 12 block diagram will aid the reader in visualizing the overall flow scheme from the storage reservoirs through the control structures, fore-bay, turbines, and surge chamber, to the tailrace tunnels and final discharge into the Lower Churchill River.

**FIGURE 11. Enlarged and detailed view of the power plant structures that lie within the circle indicated in the Fig. 10 profile.**

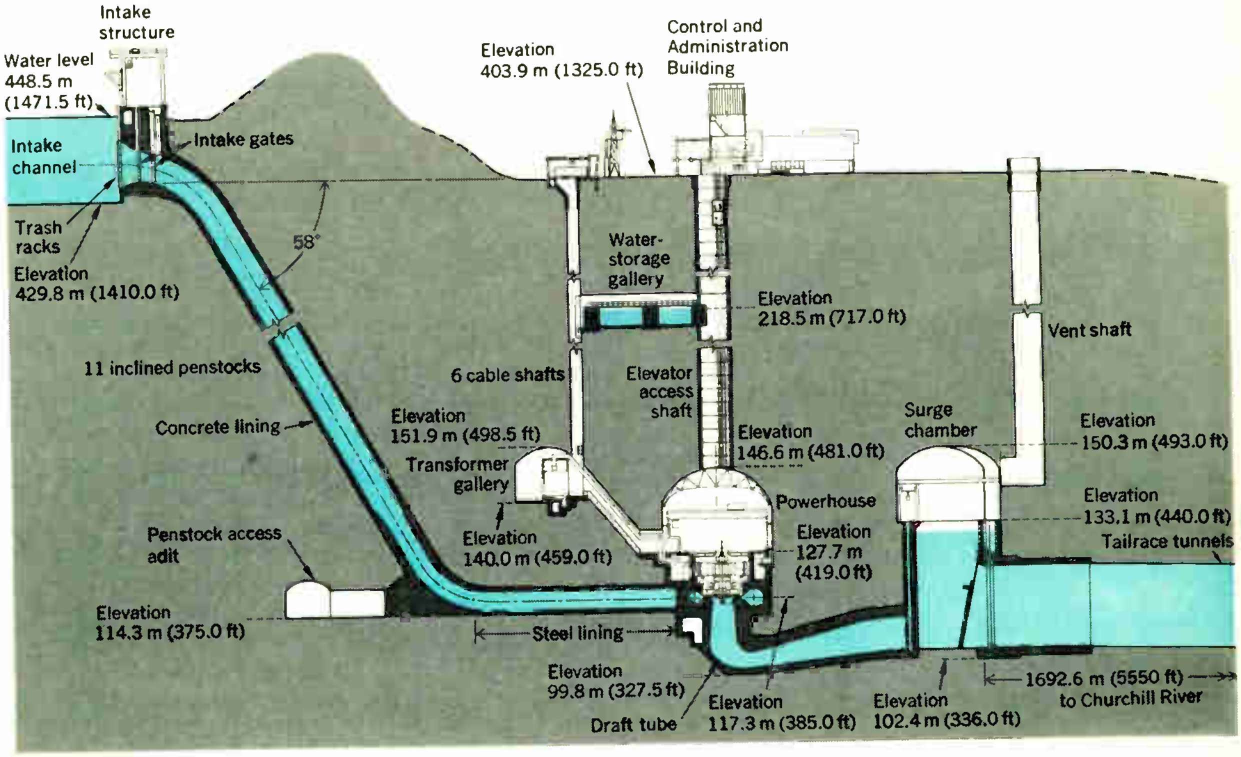
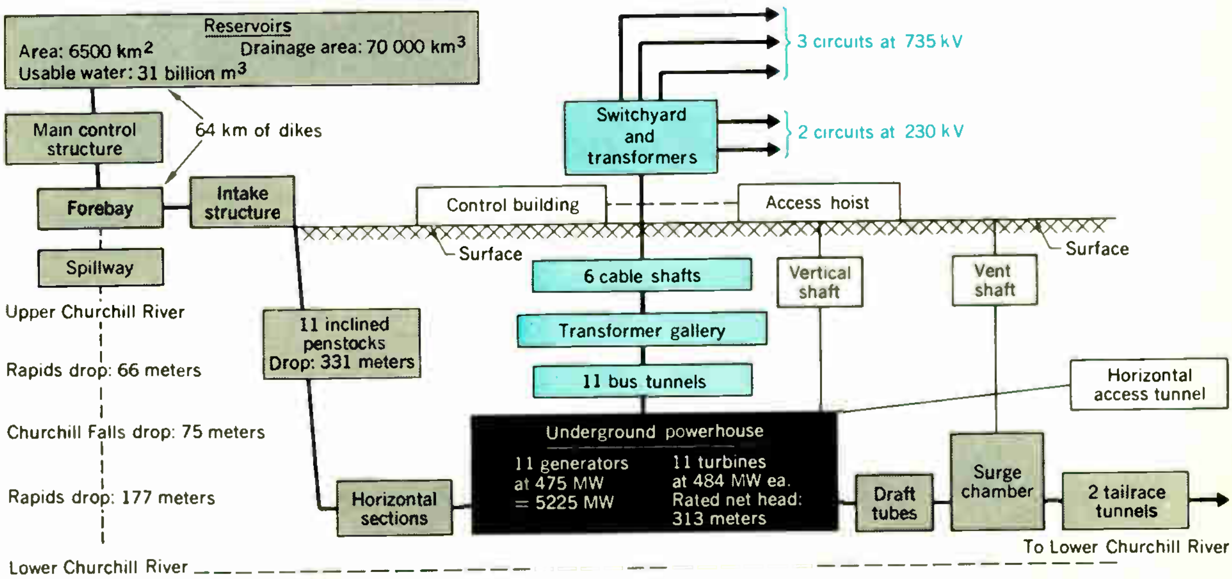



**FIGURE 12. Block diagram for assistance in visualizing the flow scheme of the entire project.**



## Physical characteristics and statistics relating to power plant and site

To afford the reader an introductory acquaintance with the immense underground facility shown in Figs. 10 and 11, a brief description of some of the climatological and geological conditions encountered at the site, plus a presentation of the salient dimensional, quantitative, and economic statistics, may be additionally helpful:

On the Labrador Plateau, temperatures vary over a broad range from −48° to +30° C (−55° to +87° F), giving an annual average of −4° C (25° F). The vegetation of the area is a shallow muskeg and an irregular low spruce forest growth. The surface geology consists of irregular glacial deposits of silty sand, gravel, and boulders in random stratums up to 12 meters in thickness in the vicinity of the power site. The bedrock geology is primarily metamorphic granitic gneiss, intruded by gabbro-diorite and incised by stable faults that parallel and intersect the Lower Churchill River.

**Optimum design and siting of power installations.** Preliminary studies of various sites soon resulted in the selection of the present location for the power installations as most practicable and economical. Thus the final plan of the plant layout, designed to produce optimum cost economies compatible with the acceptable regulation of the generating units, remained to be resolved. The study refinements for this solution are graphically illustrated in Fig. 13.

The underground powerhouse (Fig. 14), which will be the world's largest, is 296 meters long, 47 meters high, and 25 meters wide, and the invert elevation of the draft tube under the turbogenerators is about 305 meters below the grade elevation of the Control and Administration Building (see Fig. 11).

The underground excavation work called for the removal of 1.8 million cubic meters of rock, with an axial length of about 13 km. Virtually all of this subsurface work was completed by mid-1970. (For a summation of power installation statistics, see Table I.)

**Intake and penstocks.** Maximum structural economy

**FIGURE 13. Graphic presentation of study designed to produce optimum cost economies compatible with the acceptable regulation of the generating units.**

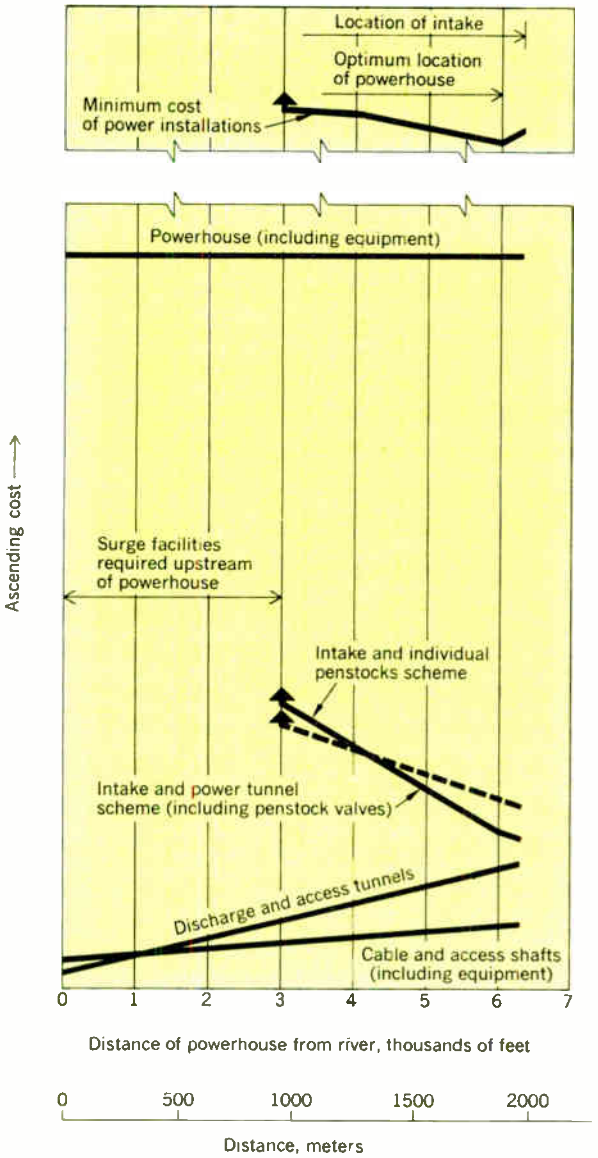
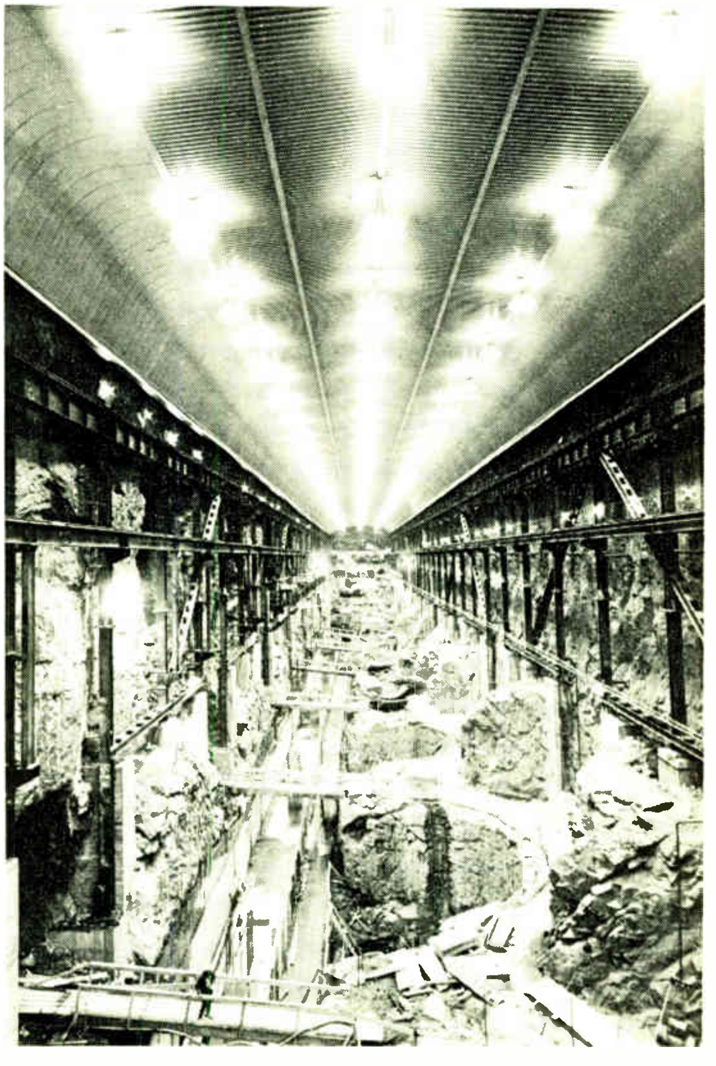



**FIGURE 14. View of the powerhouse after the completion of excavation. This underground chamber, which will be the world's largest generating facility, is situated about 300 meters below grade.**



**I. Power installation statistics**

| | |
|---|---|
| **Gross head** | 324 m |
| **Generating units:** | |
| Number | 11 |
| Rated output | 475 MW |
| **Turbines:** | |
| Rated net head | 313 m |
| Rated output | 484 MW |
| Rated speed | 200 r/min |
| Runaway speed | 330 r/min |
| Scroll case inlet diameter | 4.45 m |
| Runner inlet diameter | 5.75 m |
| Runner throat diameter | 4.35 m |
| Runner weight (approx.) | 90 tonnes |
| Total weight (approx.) | 1225 tonnes |
| **Generators:** | |
| Rated capacity | 500 MVA |
| Rated voltage | 15 kV |
| Power factor (overexcited) | 0.95 |
| Synchronous reactance | 100 percent (max.) |
| Transient reactance (unsaturated) | 33 percent (max.) |
| Inertia constant (H factor) | 3.5 (min.) |
| Rotor diameter | 9.0 m |
| Rotor weight (each) | 594 tonnes |
| Stator core depth | 3.0 m |
| Total weight (approx.) | 1090 tonnes |
| **Penstocks:** | |
| Number | 11 |
| Length | 428 m |
| Internal diameter | |
| Concrete lined | 6.1 m |
| Steel lined | 4.45 m |
| **Powerhouse:** | |
| Maximum length | 296 m |
| Maximum width | 25 m |
| Maximum height | 47 m |
| **Surge chamber:** | |
| Length | 233 m |
| Width | 12 to 19.5 m |
| Height | 45 m |
| **Vent shaft:** | |
| Diameter | 6.1 m |
| Depth | 253 m |
| **Tailrace tunnels:** | |
| Number | 2 |
| Width | 13.7 m |
| Height | 18.3 |
| Avg. length (each) | 1692 m |
| **Transformer gallery:** | |
| Length | 261 m |
| Width | 15.3 m |
| Height | 11.9 m |

was achieved by the close spacing of the penstocks at the intake to reduce the structure's overall length. As the reader will note in Fig. 11, there are no penstock valves in the powerhouse; therefore, to prevent wire drawing at the wicket gates (which is possible under conditions of high head), the intake gates must be closed each time a turbogenerating unit is shut down. Normally, these gates are operated by ac power; but, under emergency conditions, they will fall closed under the gravity of their own weight.

Penstock diameters of 6.1 meters for the concrete-lined sections and 4.5 meters for the steel-lined portions were found to be the optimum both technically and economically. The latter diameter is also the measurement of the turbine inlet. The bedrock condition throughout the penstock area is very sound, thus no significant or adverse faults requiring special treatment were found. The steel liners in the downstream sections of the penstocks are designed to take full internal pressure, and the upstream sections in concrete are designed to take full penstock pressure externally.

**Access tunnel and elevator shaft.** Access from the surface to the powerhouse for construction, and thereafter for the heavy hauling of material, is gained through a tunnel 10 meters wide by 8.5 meters high. Access from the Control Building for both personnel and small loads is provided through a vertical elevator shaft at the east end of the powerhouse. Both the tunnel and the shaft were driven simultaneously. The 6.1-meter-diameter elevator shaft was arranged so that the mucking hoists could be left in place during the powerhouse excavation work and still permit the installation of the permanent elevator. The cab of this lift can accommodate 60 men or a maximum load of about 6 tonnes. Its hoisting speed is approximately 300 meters per minute. A portion of this vertical shaft will be utilized to accommodate control cabling between the generating units and the Control Building, and for ductwork to carry 980 $m^3$/min of make-up air for the powerhouse's ventilating system.

**Powerhouse and surge chamber.** The most demanding aspect in the design of the powerhouse was the criterion of providing safe and economic deep vaults to accommodate the turbogenerator units and their ancillary equipment—busses, cables, etc. Thus, from the outset, the utmost importance was accorded to the exploratory effort in selecting a location free from rock faults, shear stratums, or other unfavorable geological conditions. Therefore, a full-scale geological mapping program was undertaken while the excavation of the access tunnel and elevator shaft was under way, and any new information was compared against the original exploratory data. A computer analysis program technique was established for ascertaining the rock modulus and rock stresses so that the final design for the arch roofing over both the powerhouse and surge chamber could be made.

The surge chamber is used for the dual purpose of channeling the discharge flow from the draft tubes to the tailrace tunnels and providing retention capacity during hydraulic surges. The dimensions of this chamber (which are given in Table I) were determined on the basis of

1. Surge analyses, employing digital computer techniques, for the solution of the fundamental equations of hydraulic mass oscillation.
2. Model tests for optimum hydraulic arrangements.
3. Evaluation of the rock stresses for various shapes of the chamber.

Hydraulic loss reductions were achieved by providing approximately horizontal vanes at spaced intervals along the walls of the chamber just above the draft tube roof level.

**Tailrace tunnels.** The two tailrace tunnels are unlined since they are cut through predominantly sound rock. Their dimensions (see Table I) were established by three criterions: minimum hydraulic loss, flow velocity, and economy of construction. The tunnel sizes are sufficient

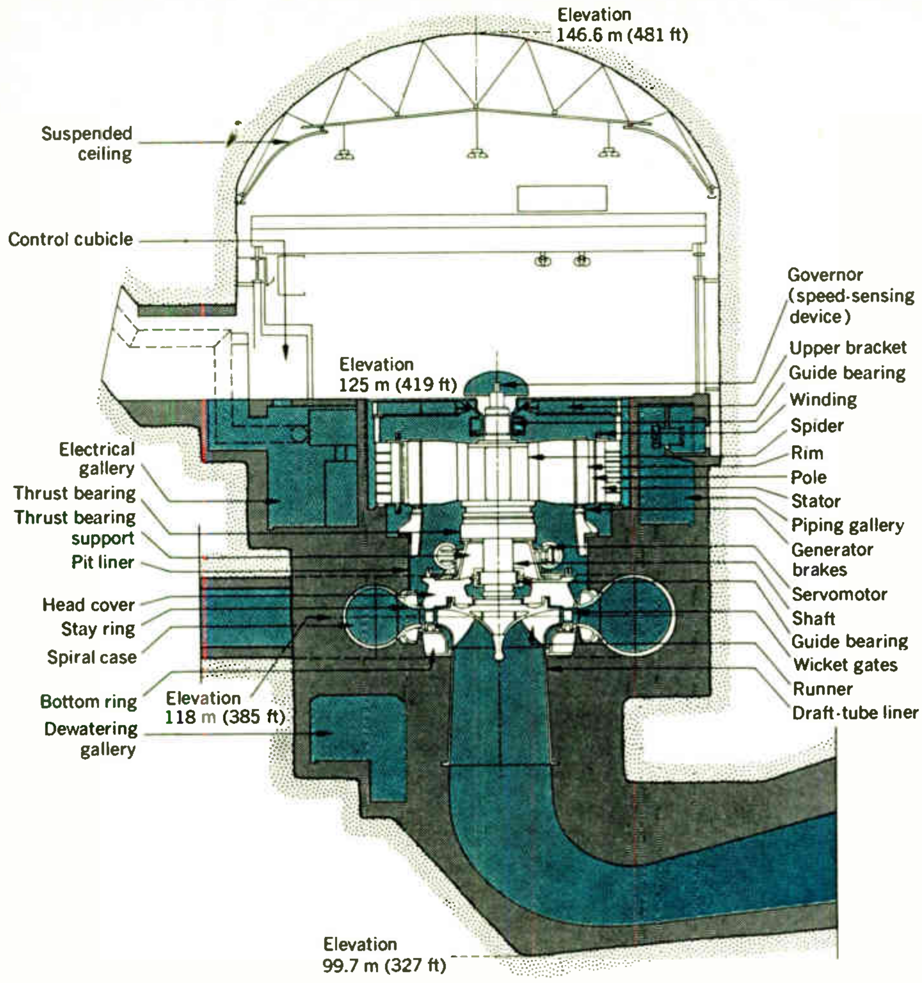



**FIGURE 15. Typical cross section through a turbine and generator unit. The hydraulic turbines are of the Francis type. Each generator is rated at 475 MW.**

to permit virtually full power plant output capacity even if one tunnel is taken out of service. Both the inlet and outlet portals of each tunnel will be provided with concrete structures that are designed to permit unwatering.

## Rotating machinery and electric equipment

**Turbines and generators.** Eleven turbogenerators form the nucleus of the Churchill Falls power plant. The machines have been ordered from a consortium that consists of Marine Industries Limited (MIL), Canadian General Electric (CGE), and Dominion Engineering Works (DEW). Under the agreement, MIL will supply five turbines and five generators, CGE five generators, and DEW five turbines. Suppliers of the eleventh unit, among consortium members, will be decided later. All turbines and generators are compatible with each other regardless of manufacturer.

Each generator will be rated at 475 MW, or 500 MVA, at 15 kV. These units will operate at a power factor of 0.95 at 60 Hz and 200 r/min. They will be three-phase and will be driven by hydraulic turbines of the Francis type, rated at 484 MW at a net head of 313 meters. Figure 15 shows a typical cross section through a turbine and generator. Each generator will have two transformers connected to its terminals, one of which will supply the static excitation system; the other will furnish the essential unit services.

Models of each of the turbines were tested in the design shops and also at the National Engineering Laboratories in Scotland. The results of the efficiency, cavitation, and flow-stability tests are reported to be very satisfactory.

**Transformers and switching.** An important decision that had to be made in the early phases of the plant design was the selection of a scheme for raising the generator output voltage to the transmission-line voltage of 735 kV. The method, which was ultimately adopted, consists of a dual system of step-up transformers. The first step-up, from 15 to 240 kV, is accomplished in 11 three-phase transformers (one for each generating unit) that are located in the transformer gallery shown in Fig. 11. The electric energy is transmitted from the generators to these underground transformers by means of a forced-air-cooled isolated-phase bus rated at 15 000 volts, 22 500 amperes. Each unit transformer is rated at 500 MVA, 60 Hz, 14 750–240 000 volts.

From the transformer gallery, the energy is brought to the surface through the six vertical cable shafts (Fig. 11), each of which is about 275 meters long. Five shafts contain two 3-phase circuits each, and one shaft contains one 3-phase circuit. The circuits consist of three 245 000-volt low-pressure oil-filled cables terminated at each end by potheads. The 230-kV switchyard is arranged to connect two units to a 230- to 735-kV step-up transformer bank (for a total of six banks), each of which consists of

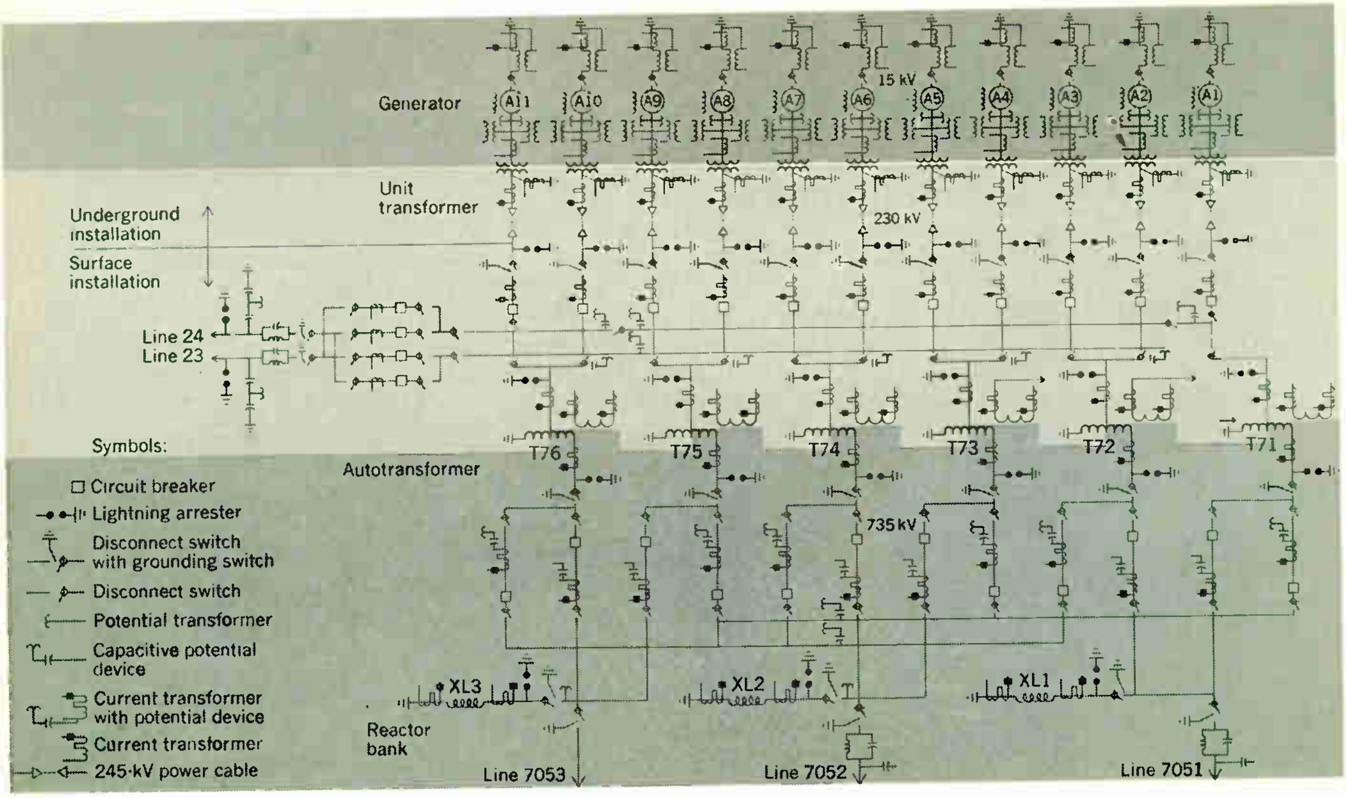



**FIGURE 16. Line diagram showing the arrangement of the unit system for the generator-transformer connections, and the 230- and 735-kV switchyards.**

three single-phase transformers rated at 333 MVA, 715 000/236 000/13 800 volts. The Fig. 16 line diagram shows the arrangement of the unit system for the generator–transformer connections and the 230- and 735-kV switchyards.

Connection to the existing Twin Falls system, which supplies Wabush and Labrador City, is also effected from these switchyards.

**Transmission system.** The selection of three 735-kV transmission lines from Churchill Falls, connecting to the Hydro-Quebec system 200 km away, was made in 1967, following more than one year's successful experience with this voltage on the Manicouagan–Montreal system. Also, special stability studies for the new transmission, undertaken by Hydro-Quebec, lent further weight to the choice. Thus there will be three 735-kV lines, each carrying three phases in bundles of four 3-cm-diameter steel-reinforced aluminum conductors.

An extensive program of aerial photography, photo interpretation, and photogrammetric techniques aided the engineers in selecting the best route for the transmission lines and the optimum design of the transmission towers. Following this, an 8-km-wide route corridor was superimposed on the high-altitude aerial photographs. Then, a delineation of the various soil conditions encountered along the route was made on a 900-meter-wide strip selected from the corridor.

Based on this information, a computer program was evolved for transmission tower spotting (averaging two towers per kilometer). Data obtained from photo interpretation and the computer program were checked with ground surveys to establish final tower positioning in both plan and profile. Considerations of severe climatic and adverse soil conditions, plus favorable economics, led to the selection of V-type guyed towers (Fig. 17). Tower foundations were designed to minimize the effects of frost heaving and all tower guy anchors underwent load tests prior to the erection of the towers.

Three 55-Mvar, single-phase shunt reactors will be connected to each of the transmission circuits to compensate for the capacitative effect of the lines. Similar reactors have been installed at each line terminal on the Hydro-Quebec system.

### Communications

The communications system providing the necessary control and protection facilities between the Churchill Falls generating station and Hydro-Quebec's electrical networks consists of a 12-hop microwave system with two hops using the tropospheric scatter method of propagation, and a power-line carriers system consisting of three links on the 735-kV transmission lines.

All major work sites in the far-flung project area are connected by Bell Canada to the North American telephone network. This is achieved by means of a link with Bell's tropospheric scatter system (Fig. 18) that serves northeastern Canada. This makes direct-dialing long-distance service available to more than 750 project telephones. Bell also provides TWX facilities, mobile radiotelephone service, and a local emergency fire and security reporting system. Canadian National furnishes telegraph and Telex service.

### Control and Administration Building

According to CFLCo's weekly newsletter of August 29, 1970, "two men comfortably seated before miniaturized

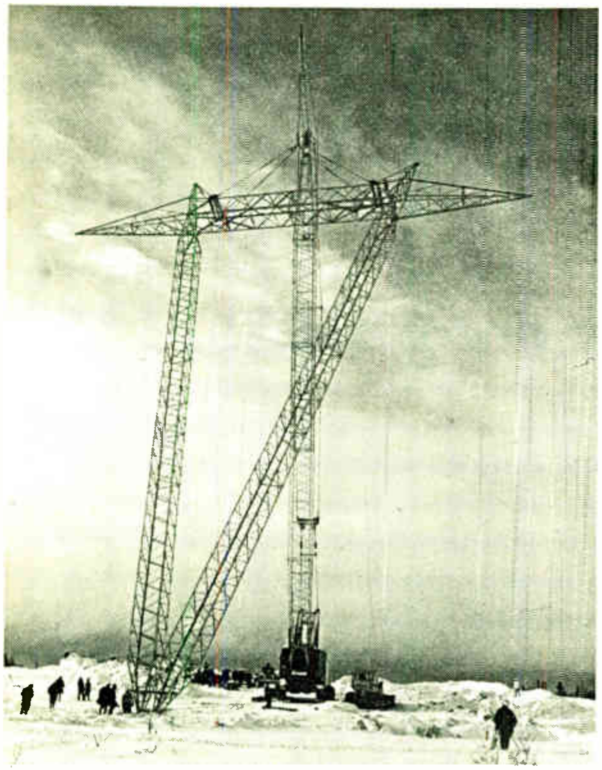


FIGURE 17. One of the guyed V-type 735-kV transmission towers shown during its erection.

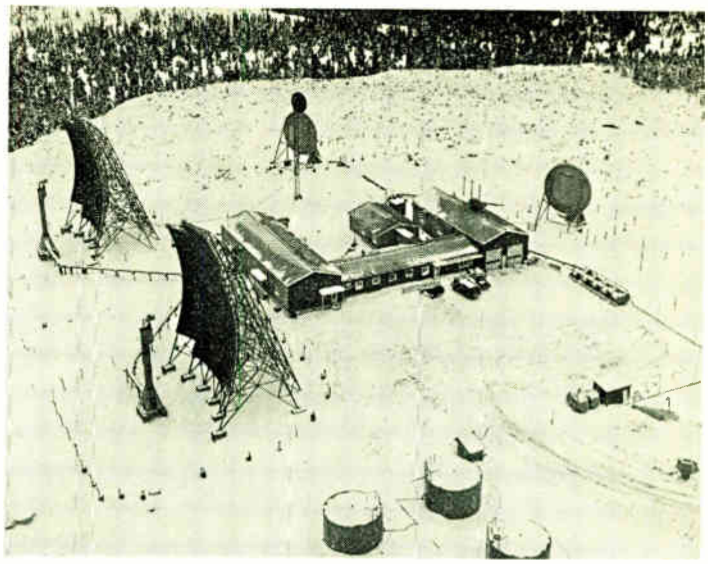


FIGURE 18. View of Bell Canada's microwave communications facility near the Churchill Falls site.

consoles and control boards in a carpeted, air-conditioned room . . . in a relatively small building situated near the edge of the Labrador Plateau . . . will be the only staff needed, under normal conditions, to operate the world's largest powerhouse."

Each of the 11 generating units will have its own adjacent control panels within the powerhouse for the control, protection, and governing of its service operation. Normally, however, the supervision and control of the units (as well as the reservoir, switchyard, and transmission facilities) will be effected from the above-grade C&A Building.

**The control room.** The "nerve center" of the power plant operation will be situated within the control room on the second floor of this structure. In this room, the pushing of a single button will be sufficient to start up any generating unit and synchronize it into the system. A Canadian Westinghouse PRODAC 2000 computer will have the capability of monitoring hundreds of functions in the huge plant, its reservoirs, and its transmission system. It will also log and transmit all pertinent data and forewarn of possible operational emergencies in the power plant area.

Control panels and analog sensors, plus backup annunciator warning systems, for the generator units and the switchyards, will be wall mounted. The room will also contain supervisory control panels for the remote operation of the water flow-control structures and for the 230-kV Wabush Lake terminal station. Ancillary equipment will include chart recorders and high-speed printout units. The operators will be virtually self-sufficient within their section of the building while on duty.

## The permanent town site

The total operating and maintenance group at Churchill Falls will number about 150. With their families, plus service personnel, it is expected that the population of the permanent community will be approximately 1000.

The town site presently consists of 59 individual houses and four apartment buildings, for a total of 107 permanent dwelling units. The most interesting and novel ideas for living in a far-northern community are to be found in the Town Centre, a multipurpose building that houses under one roof a nine-grade English and French school, small hotel, gymnasium, supermarket, cinema, and various other shops and recreational facilities.

## In conclusion, an editorial evaluation

Churchill Falls is a grand-scale development literally carved out of the bedrock of a subarctic region. It is indicative of the herculean effort that our technologically oriented civilization must undertake, even in hostile and remote climatic environments, to fulfill the ever-increasing demand for electric energy. Churchill Falls is the North American analog of the huge hydro projects built by the Russians in central Siberia.

Although hydroelectric schemes are very costly—the Churchill Falls development, including transmission, will run to more than $1 billion—they are the least harmful type of installation to the environment in terms of air and water pollution. Yet, one of the nagging aspects of Churchill Falls is its remote location and the long transmission lines to existing load centers. Although industrial growth and the parallel demand for firm power in western Labrador is increasing, Churchill Falls is still a long distance from Quebec City and Montreal. One wonders, therefore, about service reliability, maintenance, and other problems that may be encountered under the adverse seasonal climatic conditions and terrain over this vast area of northeastern Canada.

The target date of the first delivery of power from the project is May 1, 1972; the completion of the entire development is scheduled for 1976.

# Industry–university cooperation:

## a way to stem the loss of freshman engineering students

***Engineering faculties have always shied away from including real design experience in the first two years of the academic program; now Arizona State has broken the tradition, with impressive results***

**George C. Beakley, John F. Bregar** Arizona State University

*Each academic year more than 100 engineers from the Phoenix metropolitan area participate in the freshman engineering program at Arizona State University either as technical consultants or as jury members for the semester design competition. Although this program requires the use of consultants and judges, the benefits of the joint effort extend far beyond these important functions. The freshman engineers are provided an opportunity to talk to practicing engineers on a personal and informal basis and at a time when their own ideas about engineers and engineering are still very hazy. The combination of faculty and experienced engineers working together with students on a common project, with each of the participants contributing in his area of interest and specialization, has established a spirit of mutual understanding and respect.*

At a time when engineering enrollments are declining nationally, the faculty at Arizona State University has devised an effective way to rescue freshman students from alienation with engineering as a profession. In fact, at A.S.U. losses that just a few years ago ran as high as 65 to 70 percent of the freshman class by the beginning of the sophomore year have been cut in half. In addition to this achievement, the new freshman program has brought about some unanticipated side effects, such as enhanced industry–academic cooperative effort, which have proved to be equally valuable.

In 1964–65 an analysis of those students dropping engineering revealed that many had high grade-point averages. Transfers to mathematics, chemistry, and physics were particularly popular and, in general, the students expressed disappointment that they had not been given an opportunity to learn more about engineering and the "type of work that the engineer does." They indicated displeasure at finding a minimum of help (in this regard) from the freshman curriculum. At this point it was decided that the engineering faculty would organize a freshman engineering course whose primary objective would be to increase student motivation toward engineering as a career. Since the program had to be designed to accommodate large volumes of students (up to 400 per semester), since a large number of senior faculty members with extensive design experience could not be made available readily to staff such a course on a continuous basis, since the School of Engineering budget provided a minimum of funds for experimental programs, and since a "personal experience with engineering design" for the freshman student was deemed to be essential,[1] the task facing the faculty might have seemed insurmountable. Not so! Within a short time a new type of course was organized that brought about the desired results. This is the sixth year of operation of that course. Basically, its format has remained unchanged since its inception, but slight modifications and alterations have been made each semester. Arizona State's experience probably could be repeated at many other schools where freshman attrition is a problem. In fact, since the inception of the program at A.S.U. in September 1965, a number of other colleges and universities have initiated similar programs. In all known instances, the results achieved have been equally gratifying.

Any faculty member who has taught engineering design, whatever the academic level, can attest to its effectiveness as a motivational instrument. For years other professions, such as medicine, law, divinity, and architecture, have effectively provided their young neophytes with realistic experiences in the profession. In former years, young medical students made use of cadavers to clarify their understanding of the organization and function of the human body. Today this practice is continued, but in addition they participate personally in the diagnosis of live-patient disorders, assist in the delivery of babies, and in general get deeply immersed in professional aspects of the business early in their education. Of course, the student work is closely monitored by

FIGURE 1. Each student company design report is analyzed and evaluated by a panel of engineers from industry.

FIGURE 2. Working design models are frequently used by the students to prove the feasibility of their designs.

members of the practicing profession. Traditionally, engineering faculties have shied away from including real design experiences in the first two years of the academic program. Not the least of the reasons for this decision has been the widespread opinion that "freshman and sophomore students do not have the knowledge or ability to design." The A.S.U. experience would seem to indicate that such conclusions are incorrect.

## The program

Although it was recognized to be a break with tradition, a course in creative design was inaugurated for first-semester freshmen. The types of design experiences emphasized are conceptual design and feasibility design studies. In the three-semester-hour course the students meet three 50-minute periods per week. On one of these days all students meet jointly in a lecture hall to hear an invited speaker relate his personal experience pertaining to the design of some engineering device, system, product, or process. Each of the other periods is spent in a classroom, with an instructor and not more than 30 students. Through experience it has been found that, with proper guidance, young graduate assistants make excellent teachers for this type of course. They seem to establish much better rapport with the students than many of the older professors. Also, they are more inclined to have a real interest in working with the young student. For this reason, over half of the instructors in this course usually are doctoral candidates in engineering.

Authenticity and realism are added to the design experience by the early announcement to the students of the organization of a syndicate of multimillionaires—Idea, Inc. (Invention Development Engineers of Arizona). *In actuality Idea, Inc., exists only as a figment of the imagination—with the corporate members being the instructors of the several course sections.* Explanation is made to the students that this syndicate is searching for and will invest in: (1) new products, designs, inventions, processes, systems, or modifications of existing ideas; and (2) young engineering companies that evidence promise in such areas as engineering proficiency, initiative, general organizational capability, creative resourcefulness, and judgment. Each student participates in both aspects of this search, which culminates in the semifinal and final competitions.

In the freshman engineering design project each student must accomplish the following:

1. Generate a design problem (identify some physical need that does not appear to be met satisfactorily today).
2. Submit a proposal for authorization to organize an engineering company (students submitting best proposals are appointed as chief engineers who assume leadership of a company effort to undertake the development of a proposed system or device).
3. Serve as one of five or six student engineers in a company effort to (a) identify the problem; (b) analyze the problem, specifying design and criterions and restrictions—both technical and economic; (c) brainstorm for possible solutions; (d) make decisions concerning optimum choices of available alternatives; (e) identify critical components and elements in the systems of devices envisaged; (f) design some components and specify others; (g) make market surveys and economic evaluations, usually with the assistance of a marketing consultant; (h) prepare and deliver oral and written progress reports to superiors; (i) consult with engineers from local industries who have volunteered to provide such assistance; (j) prepare a final design report and appropriate visual aids for the oral presentation; and (k) build a working model, if possible.
4. Take an active part in a student-led, engineer-guided design competition that concludes with a semifinal and final competition.

This design project offered a unique opportunity to develop a cooperative program with the College of Business Administration. Senior marketing students are assigned as advisors to each section of the course. They advise the freshman student companies on the techniques of conducting market surveys and generally assist in the market analysis. The marketing students are expected to prepare a semester report of their activities as part of their marketing course requirements. Not only do the engineering students gain an insight into marketing problems, but the marketing students learn something about the complexities of the engineering profession.

The design competitions are held near the end of each semester. For the semifinal competition, a panel of judges is assigned to each class. After reviewing the written reports (Fig. 1), the judges listen to an oral presentation from each of the companies (Fig. 2). The winning company from each class—determined by the jury—then enters a final competition. The panel of judges for the final competition is composed of representatives from academic institutions, top-level industrial management, and professional consulting engineers (Fig. 3). The winning student company is presented with a handsome trophy and each company member receives a certificate of achievement. Winning companies also receive considerable recognition from the local community through television and newspaper coverage.

**FIGURE 3. Jury members for the final competition are engineers who hold executive management or design positions within their respective companies.**

## Industry-university cooperation

Early in the development of the program it was recognized that some additional assistance was needed from engineers who were themselves experienced in engineering design. This was particularly evidenced in those classes whose teachers were young graduate students. Inquiries as to the interest of engineers who worked in local industries about helping the freshman students brought an unusually favorable response. In fact, almost 500 engineers, all members of local engineering technical societies (IEEE, ASME, ASCE, AIChE, etc.), volunteered to serve the student companies as consultants in their own particular areas of engineering specialization. No one engineer is asked to serve as a consultant to more than one student company in a given semester, or more frequently than once per year. Whenever students need assistance with some specific aspect of their design, a suitable industry consultant is selected from the composite file, which is maintained by the faculty course coordinator. After receiving the assignment of the consultant, the chief engineer of the student company is responsible for contacting the engineer to arrange a mutually convenient meeting to discuss the design difficulty.

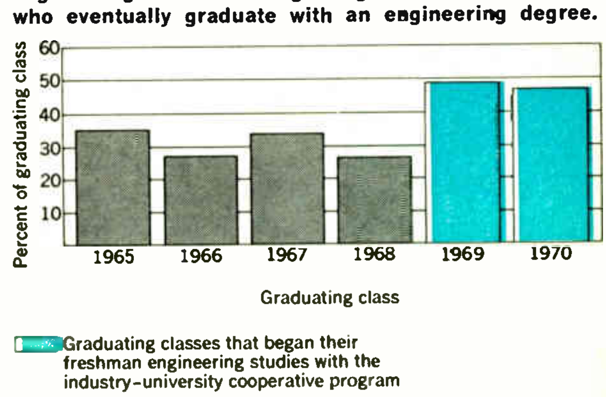
The results have been excellent. The consultants have responded well to the enthusiasm of the students and always seem pleased to help them with their design project. The students benefit from the exposure to the real world of engineering as exemplified to them by the association with consultants from industry.

Although the consulting program seemed to work very well, a few problems soon became evident. The available pool of consultants was much too large to allow everyone to participate. Many of the engineers who responded to the initial questionnaire regarding interest in participation and who were willing to serve as consultants could not be used in this way. For example, few student projects required experience in such things as antenna design or in highway, bridge, or dam construction. Also, some engineers who were in managerial positions were far removed from the hardware end of the business. Happily, it was found that there was another phase of the program where all of these engineers could be used effectively and where their experience and judgment would be particularly useful. This was in judging the comparative quality of the 60 or more design projects that are completed each semester.

For the design competition each student company must


**FIGURE 4. Each semester the freshman design program attracts considerable press and television coverage. (Reg Manning in "The Arizona Republic")**

**FIGURE 5. The increased student retention of freshman engineering students is beginning to swell the numbers who eventually graduate with an engineering degree.**



submit a written engineering report and make an oral presentation of the design solution. Initially, faculty from the College of Engineering Sciences were asked to serve as members of design juries to review the reports carefully and to listen to the oral presentations. Since there were sometimes as many as 12 to 15 sections, the number of faculty who were willing to serve on this type of jury duty diminished rapidly after the first two or three semesters. It was recognized that some other source of judges was needed. The list of "consultants" was again brought into play and interested engineers from industry were invited to serve as jury members for the competition. Approximately five jury members per class section are needed. Those selected are engineers from local industries, construction firms, local government agencies, and consulting engineering firms. They are asked to attend a briefing at the university the day before the competition, and then to attend the oral presentation of the student companies the following day.

The initial effort proved to be an outstanding success and this feature has become a permanent part of the program. The presence of an outside jury seems to add a new dimension to the design competition. The jury from industry always takes a keen interest in the work that the students are doing and these seasoned engineers always spend considerable time in debating the merits of each of the company designs. The principal complaint heard from the juries is that they would like to be allowed more time to work with the students and to evaluate the design projects. They are always greatly surprised at the quality (relatively speaking) of the freshman engineering designs—which hasn't hurt industry–university relations in the least.

The use of engineer consultants and design juries from industry has had some unexpected side benefits. For perhaps the first time, many of these experienced engineers have been invited to participate in a university program with the engineering students where their knowledge and experience is not inferred to be out of date. Here their design expertise is sought after and their current engineering ability is acknowledged as being valuable in the educational process.

Last year the student design competition took place a few days after a minor student disturbance had occurred on the campus, which had resulted in considerable disruption to the academic activity—though fortunately no violence occurred. As had been the case on many campuses, the actions of the very small minority of undisciplined students involved in the disruption received a great deal of attention from the public news media. However, the juries of practicing engineers, some in rather high-level management positions, had an opportunity personally to see another group of university students who were busily engaged in their studies and enthusiastically bent on trying to find solutions to problems through a disciplined engineering approach. The contrast was so remarkable that the freshman engineering program also began to attract its share of television limelight. The nationally syndicated cartoonist, Reg Manning, used a political-type cartoon (Fig. 4) contrasting the two types of youth activity. This public acclaim was not unappreciated by the entire university faculty since the state legislature happened to be considering the university appropriations the day the cartoon appeared in the newspapers.

An analysis of the dropouts from engineering for the past five years indicates significantly different trends than had been experienced before the creative design program was initiated. Where for several years the transfer losses to chemistry, physics, and mathematics had been quite high, these losses are now insignificant (3, 1, and 2 percent respectively). The largest losses now go to business (30 percent) and the baccalaureate program in technology (25 percent). Next, and much lower on the scale, are losses to general liberal arts (7 percent), the B.S. program in construction (6 percent), and education (5 percent).

Figure 5 shows the composition of engineering graduating classes for four years preceding the implementation of the A.S.U. experimental program and the first two graduating classes who began their freshman year with the course in creative design. The increase in the percentage of nontransfer students who were graduated in these two years seems to indicate that a substantial number of the freshman students from 1965 and 1966 who were motivated to continue engineering for their sophomore year did, in fact, finally earn their baccalaureate degrees in engineering.


**REFERENCE**

1. Beakley, G. C., and Price, T. W., "Motivating engineering freshman through an authentic design experience," *IEEE Trans. Education*, vol. E-9, pp. 195–197, Dec. 1966.


**George C. Beakley** received the B.S.M.E. degree from Texas Technological University in 1947, the M.S.M.E. from the University of Texas in 1952, and the Ph.D. with a double major in mechanical and industrial engineering from Oklahoma State University in 1956. After working as an associate professor at Tarleton State College from 1947 to 1953, he turned his attention to design and development for Bell Helicopter Corporation (1953–54) and the AiResearch Manufacturing Corporation (1956). From 1956 to 1967 he was chairman of the Mechanical Engineering Department at Arizona State University, Tempe, where he is currently associate dean of the College of Engineering Sciences, director of engineering science, and professor of engineering. Dr. Beakley has written a number of technical papers and is the coauthor of ten college engineering textbooks. He is a member of ASME, AIIE, NSPE, and ASEE.

**John F. Bregar** received the B.S. degree in electrical engineering from Pennsylvania State University in 1948 and the Ph.D. degree in nuclear engineering from the University of Arizona in 1966. He was employed by the Westinghouse Electric Corporation from 1948 until 1953 and from 1953 to 1956 he was head of the Lighting Section for the Supervisor of Shipbuilding (U.S. Navy) at Newport News, Va. In 1957 he joined the Newport News Shipbuilding and Dry Dock Company and served in various capacities on nuclear ship construction until 1962, when he entered the University of Arizona. He is now an associate professor of engineering at Arizona State University, and also has served as course coordinator and an instructor for the Freshman Engineering Program. Dr. Bregar is the author or coauthor of several technical papers. His memberships include the American Nuclear Society and ASEE.

# New product applications

## Design manual for SCR applications adds basic theory to recent circuit developments

Relevant portions of silicon-controlled-rectifier theory have been integrated with practical circuit design discussions in the recently published Westinghouse *SCR Designers Handbook*. This is a second edition, bringing information up to date.

Principal topics in the new manual include dc switches, ac switches and polyphase converters and controllers, firing circuits, and a section on device analysis. Practical applications information is given in the section on mounting SCRs, including specific machining operations.

Suggestions are given for using blocking oscillators to provide a fast-rising gate signal for triggering the SCR. These oscillators can be used in conjunction with slowly rising voltages. Monostable blocking-oscillator circuits supply a current pulse for a prescribed input signal and the astable design generates a train of pulses unless it is inhibited.

Successful application of a blocking-oscillator trigger is related to the load current and the pulse train or pulse that is to be supplied. The relationship of gate signal for various load *di/dt*'s is compared in Fig. 1. The device delay time has been plotted as a constant although it is actually variable. It will be noted that pulse train *A* is insufficient to trigger the device. Similarly, pulse train *B* will not fire the device properly for load line *C*. The reason is that the gate signal is extinguished prior to the device reaching the latching level for load *C*. The last pulse train (C) is sufficiently wide to trigger load lines *A*, *B*, and *C*.

Another related design problem is the off space between gate pulses. If the load current slope is erratic or slightly oscillatory, the thyristor may extinguish itself. The designer must be sure that all snubber circuits or related circuit reactances do not form an oscillatory circuit.

A full-wave universal speed control using residual feedback is shown in the circuit diagram of Fig. 2. Many simple circuits suffer from motor characteristics and poor torque–speed characteristics at maximum delay. The motor problems result from low-hysteresis iron that is used in the manufacture of the motors. Such motors have low counter-EMF voltages so feedback conditions are difficult to control in production. Brush life on half-wave operation is low and half-wave control tends to fall off at low speeds. The full-wave control illustrated gives better low-speed control. The one shown uses a trigger diode and delay circuit $VR_1C_1$ to control the conduction interval. The rate circuit $R_3C_2$ removes motor noise from the gate-trigger circuit and stabilizes the feedback signal to the gate timing circuit.

Data on the thermal design are given in a separate section of the handbook. As indicated in Fig. 3, mounting procedures, heat sinks, and thermal lubricants are important and are outlined in detail. The illustration refers to the Pow-R-Disc type that is different from the usual thyristor and presents special thermal problems to the design engineer.

Contact areas between the device and the heat sink must be flat, relatively smooth, and clean. Extremely important is proper application of thermal lubricant that should be dispensed directly from a tube or using a solid applicator because brushes and cotton-tip applicators leave lint and grit, and increase the thermal resistance.

Specific circuits are given in the manual for practical devices such as battery-operated vehicle controllers, three-phase converters, ac motor controllers, battery chargers, lamp dimmers, and lighting controllers.

Copies of the new *SCR Designers Handbook* are available at $3.00 from Westinghouse Electric Corp., Westinghouse Building, Gateway Center, Pittsburgh, Pa. 15222. Residents of Canada must include an additional $1.00 to cover extra costs of postage.

**Circle No. 85 on Reader Service Card**

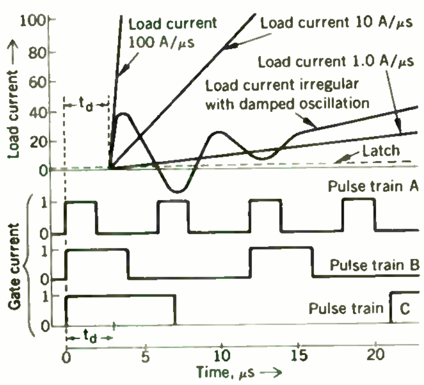



**FIGURE 1.** Blocking-oscillator gate pulse width versus various load di/dt.

**FIGURE 2.** Full-wave speed control.

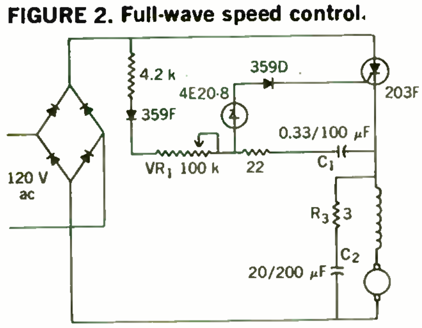
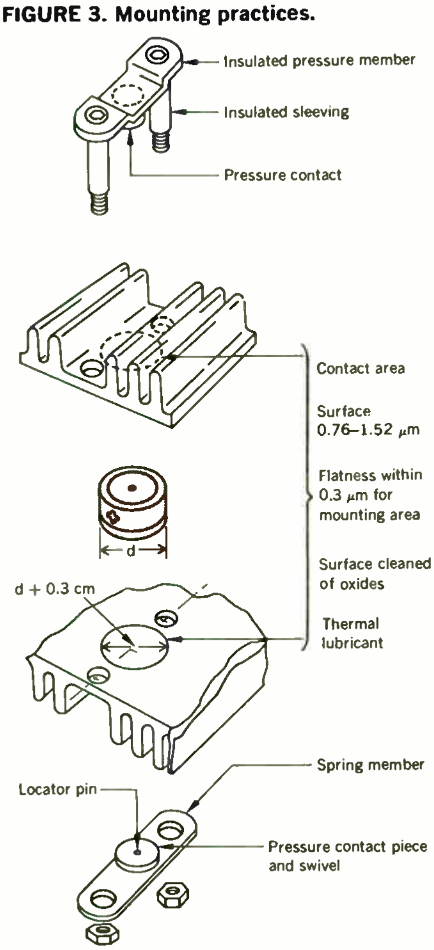



**FIGURE 3.** Mounting practices.



# Inside IEEE

## Actions of IEEE Board respond to high-priority needs expressed by the members

**A report from IEEE's President**

Your officers and directors are devoting considerable time to improving the communications networks of the Institute so that the expressed needs of individual members will get attention as rapidly as possible. Through letters and personal conversations with many members throughout the world, we have become keenly aware of the specific needs of IEEE members and we are attempting to respond rapidly to the views expressed.

We are aware that members want to know promptly what actions have been taken in response to their comments and what actions are being considered for the future. The awareness on the part of the Board is why "Inside IEEE" has been restructured to do a better and faster reporting job. This month's column, for example, is the result of special efforts that were made to include a report of the actions at the Board of Directors meeting on January 6, a date that is beyond the normal closing date for this issue.

At this Board meeting, two separate actions were taken to reduce member dues in certain cases. One action applies to unemployed members; the other to members entering the military service. Effective immediately, involuntarily unemployed members will pay only one half of regular dues ($12.50 per year instead of $25) and one half of Group and Society membership fees. Detailed information is given in the boxed notice on page 116 of this issue. Members entering the military service will now be eligible for a substantial reduction in dues while in the service. Any IEEE member who enters the military service on a full-time basis is eligible for this dues reduction. He need only submit evidence of this fact to IEEE Headquarters, and then he will be able to continue his membership with all privileges by paying only $8 annual dues instead of the usual $25. The arrangement may be continued for a total of four years.

Many members in the United States have urged the Institute to attempt to influence legislation, particularly with regard to improving the economic status of the membership, and to provide various member services directly concerned with economic betterment. Quite apart from the question of the appropriateness of IEEE participating in such activities in view of its present Constitution is a matter of organizing a concerted effort in a short time that can be expected to be truly effective in achieving the desired objectives. To provide those Institute members with an immediate opportunity to fulfill their desire for greater involvement in the nontechnical areas of the profession, the Board approved at the January meeting an arrangement with the National Society of Professional Engineers (NSPE) whereby certain services of that organization can be obtained by IEEE members at a substantial saving compared with NSPE membership dues. The charter of NSPE permits it to engage in legislative activity and to offer services related to the economic status of its members. Under one of the options available, for an annual fee of $15 an IEEE member can obtain copies of a legislative bulletin, a legislative action report, and a legislative opinion request, all of which are concerned with engineering-related national (U.S.) legislation, as well as numerous other services. Additional details are given in the boxed notice on page 116 and more information, which is omitted this month because of time limitations, will be given in the March issue. An interesting account of the activities of NSPE is given by IEEE Fellow and NSPE President Harry Simrall in this issue. It is to be noted that this action by the Board in no way precludes further consideration of IEEE action in these areas or subsequent action by the Board as a result. Indeed, I am devoting a substantial amount of my Institute time to formulating further alternatives for action in this broad area of vital member concern. The move however does provide a virtually immediate opportunity for those members who wish to take action in the nontechnical area to do so at a minimum cost. Directors, as well as Section chairmen, Group chairmen, and Society presidents, have received copies of the press release on this subject and can provide further information immediately, if desired.

In our talks with members we have also learned of their continued interest in the availability of materials for continuing education. Furthermore, we have found out that many members have not been well informed about the educational offerings presently available from the IEEE. These offerings have been publicized in the past but only on an individual basis. One could easily have overlooked one or more announcements in *IEEE Spectrum*. To rectify this communication difficulty we are presenting in Table I a complete inventory of educational services presently available. Included in the table are seminar and short course publications, slide tape lectures, cassette colloquia, IEEE Soundings, films, and video tape lectures. Complete ordering information and an order form are included. Glen Wade, Chairman of the Educational Activities Board (EAB), is presently directing his attention to the development of new educational items in the series with particular attention to applications-oriented material. He would welcome your suggestions in this connection (address him at Headquarters in New York). He is also working in cooperation with Vice President Tanner and the Regional Directors to obtain appreciable improvement of organized educational activities at the Section level.

Another development discussed at the Board meeting that has important educational implications for our membership is the creation of the IEEE Press. This new entity will be publishing special collections of reprinted papers, principally from IEEE Journals, augmented by special introductory or tutorial material. To serve the expressed interests of the total membership, present plans call for an applications-oriented series of books as well as one primarily concerned with theoretical matters. One of the first books under consideration is concerned with digital signal processing. Books in both series will be available at nominal prices, with the first book scheduled for publication in mid-1971. Others are expected to follow later this year. Ben Coates, Vice President for Publication Activities and Chairman of the Publications Board, is working closely with Glen Wade in the initiation of this venture.

The IEEE is placing increased emphasis on students and student affairs under the leadership of Vice President

## I. IEEE EDUCATIONAL OFFERINGS

### Slide Tape Lectures

On loan to Sections and Branches.
Handling charge: $2.50 to Student Branches, $10.00 to all others.
May be purchased outright at the prices listed.

| Number | Title | Price, $ |
|---|---|---|
| ***Microelectronics*** | | |
| 67-M-1 | Terminology and Classifications—S. M. Stuhlbarg | 20.00 |
| 67-M-2 | Thin Film Electronics—M. Penberg | 38.50 |
| 67-M-3 | Thick Film Networks—R. C. Early | 32.50 |
| 67-M-4 | Hybrid Microelectronic Bonding and Packing Methodology—M. Ohanian | 35.50 |
| 67-M-7 | Integrated Circuits Fabrication—C. M. Awad | 51.50 |
| 67-M-8 | Effect of Process Characteristics and Control on Integrated Circuit Design and Specifications—R. E. Bohn | 52.50 |
| 67-M-9 | Bipolar Digital Circuits—W. T. Rhoades | 39.50 |
| 67-M-10 | Practical Application of Monolithic Analog Circuits —J. F. Gifford | 41.50 |
| 67-M-11 | Microwave Applications—V. Gelnovatch | 31.50 |
| 67-M-12 | Microelectronic Packaging: Current Techniques and Future Trends—J. J. Staller | 44.50 |
| 67-M-13 | Impact of Large Scale Integration on Packaging and Interconnection of Digital Electronic Systems—J. W. Lathrop | 44.50 |
| 67-M-14 | Multilayer Wiring Technology—A. Levy | 23.50 |
| 67-M-15 | Mechanical Wiring Technology—L. Katzin | 33.50 |
| 67-M-16 | Thermal Design Considerations in Microelectronic Circuitry—J. Baum | 28.50 |
| 67-M-17 | Microelectronics Reliability—E. C. Hall | 35.50 |
| 67-M-18 | The Future of Integrated Circuits—G. R. Madland | 32.50 |
| 67-M-20 | Systems of the Future—W. W. Gaertner | 72.50 |
| ***Hybrid Microelectronics Circuits*** | | |
| 68-HC-2.2 | Thin Film Hybrid Microcircuit Interface Design Problems—H. R. Larsen | 43.50 |
| 68-HC-4.1 | Device Microassembly: An Overview—M. Ohanian | 32.50 |
| 68-HC-4.3 | Medium Scale Integration—W. P. Dean | 30.50 |
| 68-HC-5.1 | Cost Effectiveness of Microcircuit Hybrid Packaging—E. R. Mullen | 31.50 |
| 68-HC-6.2 | Microcircuit Packaging and Hermetic Sealing—G. K. Fehr | 38.50 |
| 68-HC-6.3 | Plastic Encapsulation of Hybrid Microelectronic Circuits—J. L. Hull | 58.50 |
| 68-HC-8.2 | Thin Film Applications and Case Histories—C. M. Neal | 50.50 |

Cut along dotted line

IEEE Education Registrar
345 East 47th Street
New York, N.Y. 10017
U.S.A.

Please send the following: (Please print)

| Quantity | Item—Number or Title | Amount in Local Currency |
|---|---|---|
| | | |
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| | | |

Total Amount Enclosed in Local Currency ________

Check one: ☐ IEEE Member ☐ Nonmember

IEEE Membership Number ________

Name ________

Address ________

City, State, Zip Code ________

### Seminars, Short Courses

Seminars and Short Course Publications are available at the following prices. The material listed consists of Course Notes and Study Outlines. Supplemental textbooks, available at local bookstores, are given in parentheses.

| Course number | Title | Price, $ |
|---|---|---|
| 69-E-1 | Fundamentals of Integrated Circuits ("Analysis and Design of Integrated Circuits," Motorola, McGraw-Hill; "Semiconductor Electronics Education," Committee Paperbacks, J. Wiley [5]) | 10.00 |
| 69-E-3 | Fundamentals of Reliability ("Probabilistic Reliability," M. Shooman, McGraw-Hill) ASQC/IRE Reliability Training Text, IEEE | 7.00 |
| 70-E-1 | Monolithic Integrated Circuits | 10.00 |
| 70-E-3 | Applications of Digital Filters ("Digital Processing of Signals," B. Gold and C. M. Rader, McGraw-Hill) | 7.00 |
| 70-E-4 | Using Quantum Electronics Today | 10.00 |
| 70-E-5 | Computers and Patient Care (Study outline only included) | 5.00 |
| 68-E-1 | Computer Programming for Electrical Engineers | 10.00 |
| 68-E-2 | Problem Solving for Electrical Engineers Using Time-Shared Computers ("Fortran with Engineering Applications," D. D. McCracken, J. Wiley) | 10.00 |
| 70-E-6 | Fundamentals of Supervisory Control | 5.00 |

### Cassettes

For sale to individual members and nonmembers.

| | | Price, $ M | Price, $ NM |
|---|---|---|---|
| ***Cassette Colloquia*** | | | |
| IPL-69 | Workshop on Computer Languages for Process Control | 6.00 | 10.00 |
| 70-CC-01 | The Future of Air Traffic Control | 7.00 | 12.00 |
| 70-CC-02 | Management Principles for Engineers | 6.00 | 10.00 |
| 70-CC-03 | Integrated Circuits for Consumer Applications | 7.00 | 12.00 |
| 70-CC-04 | Principles for Programming Process Computers | 6.00 | 10.00 |
| ***IEEE Soundings*** | | | |
| | An annual subscription service consisting of four cassettes per year. | | |
| | Subscription | 26.00 | 42.00 |
| | Individual cassettes: | | |
| 70-ES-01 | Systems Engineering: Art, Science and Politics | 7.00 | 12.00 |
| 70-ES-02 | Electronics in Commercial Aviation | 7.00 | 12.00 |

### Films

The National Committee for Electrical Engineering Films has made available to the IEEE Film Library the following films. Available on a loan basis, a handling charge of $10.00 has been established.

- Movies from Computers
- Electromechanical Dynamics of Synchronous Machines
- Complex Waves I
- Complex Waves II
- Wave Velocities, Dispersion, and the Omega–Beta Diagram
- Harmonic Phasors
- Response of a Resonant System to a Frequency Step
- Introduction to the General Purpose Oscillosope

Additional titles in the Film Library include:
($5.00 handling charge)

- Artificial Intelligence—Present and Future
- Traffic Control
- Controlled Thermonuclear Fusion and Electrical Engineering
- Engineering—The Challenge of the Future (Guidance film—postage only)

### Video Tape Lectures ($10.00 handling charge)

- Workshop on Thick Film Hybrid IC Technology (two reels)
- What Are You Going To Do for Me in the 70s IEEE?

## Exchange rates

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| U.S. dollars | $25.00 | $10.00 | $5.00 | $1.00 | 75 cents | 50 cents | 25 cents |
| Francs[1] | 140 | 56 | 28 | 5.60 | 4.20 | 2.80 | 1.40 |
| Italian lire[2] | 15625 | 6250 | 3125 | 625 | 470 | 313 | 157 |
| British pounds/ shillings/pence[3] | 10/8/4 | 4/3/4 | 2/1/8 | 0/8/4 | 0/6/3 | 0/4/2 | 0/2/1 |
| Spanish pesetas[4] | 1736 pta | 694 pta 44 ct | 347 pta 20 ct | 69 pta 44 ct | 52 pta 08 ct | 34 pta 72 ct | 17 pta 36 ct |
| Yen[5] | 9000 | 3600 | 1800 | 360 | | 180 | 90 |
| Deutsche marks[6] | 91 m 50 pf | 36 m 60 pf | 18 m 30 pf | 3 m 66 pf | 2 m 75 pf | 1 m 83 pf | 92 pf |

(A) Checks should be made payable to:

1. Bank check: Chase Manhattan Bank for the Account of The Institute of Electrical and Electronics Engineers.
   Postal check: "C.M.B. Postal Check Account: Paris 11–99": the correspondence stub must indicate "For the Account of IEEE"
2. Banca Nazionale del Lavoro for the Account of The Institute of Electrical and Electronics Engineers
3. Chase Manhattan Bank for the Account of The Institute of Electrical and Electronics Engineers
4. Chase Manhattan Bank for the Account of The Institute of Electrical and Electronics Engineers
5. Chase Manhattan Bank for the Free Yen Account of The Institute of Electrical and Electronics Engineers. (Form 1-A must be prepared in triplicate and submitted with payment. Write IEEE Hq. for forms.)
6. Chase Manhattan Bank for the Account of The Institute of Electrical and Electronics Engineers

(B) Send the order form and payment in your local currency directly to:

1. Chase Manhattan Bank, 41 Rue Cambon, Paris 1er, France
2. Banca Nazionale del Lavoro, 119 Via Vittorio Veneto, Rome, Italy
3. The Chase Manhattan Bank, N.A., P. O. Box 440, Woolgate House, Coleman Street, London E.C. 2, England
4. Banco Hispano Americano, Casa Central, Madrid, Spain
5. Chase Manhattan Bank, C.P.O. Box 383, Tokyo, Japan
6. The Chase Manhattan Bank, N.A., 6 Frankfurt/Main 1, Germany, Postfach 3994

Note: IEEE order form, in every instance, must accompany your payment to the bank to insure proper identification and proper credit when it is transmitted by the bank to IEEE Headquarters. It will not be possible for the bank to take action unless an IEEE order form is submitted with your payment.

Tanner. For example, membership requirements have been simplified for all students contemplating a career in the electrical/electronics profession. As a result of action taken at the January Board meeting, there is now just one grade of Student member. The Student Associate category has been eliminated, and as a result Student Branches will include the former Student Associate Branches. The term "school of recognized standing" has been redefined to include bona fide community colleges, junior colleges, and technical institutes with appropriate accreditation. The transfer of the Student Activities Committee to the Regional Activities Board (consisting primarily of Regional Directors) at the beginning of the year has enabled interaction at the first meeting of this Board in January, which should yield much greater attention to student activities in the various Sections of the Institute.

Repeatedly there was emphasized at the Board meeting the need for substantial increase in attention to the service rendered to the individual member. Good communications between the many volunteers with positions of responsibility and the permanent Headquarters staff are of paramount importance in developing understanding of member needs and responding to them. The appointment of Charles F. Stewart, Jr., to the Headquarters staff as Staff Director, Membership Activities (see page 119 of this issue), provides a Headquarters pivot for the vital Region–Section communications network. He will be working closely with Vice President Tanner, the Regional Activities Board, and staff members Emily Sirjane and Esmi Bidstrup with the primary objective of seeing that the Institute increases both the speed and effectiveness of the service to its members.

Your comments regarding the new format of "Inside IEEE" will be welcomed. You may pass them on to me directly, either in writing or personally at one of the many meetings I will be attending in the near future, or, alternatively, you may wish to express your views to your Section, Group, or Society officers or to one of our Regional or Divisional Directors.

*J. H. Mulligan, Jr.*
*President, IEEE*

## John Bardeen wins IEEE Medal of Honor; Major Annual and Prize Paper Awards are also announced

John Bardeen, professor of electrical engineering and physics at the University of Illinois in Urbana, is the 1971 recipient of IEEE's highest award, the Medal of Honor. The winners of the other IEEE Major Annual Awards and the Prize Paper Awards have also been announced. All awards will be presented at the 1971 IEEE International Convention in New York City on March 22–25.

The Major Annual Awards winners are the following: *Edison Medal*—John Wistar Simpson (F); *Founders Award*—Ernst Weber (F); *Lamme Medal*—Winthrop Moorhead Leeds (F); and *IEEE Education Medal*—Franz Chaim Ollendorff (F). The Paper Prize Awards recipients are as follows: *W. R. G. Baker Prize Award*—Andrew H. Bobeck (M), Robert F. Fischer, Anthony J. Perneski (M), Joseph P. Remeika, and L. G. Van Uitert; and *Browder J. Thompson Memorial Prize*—Lloyd J. Griffiths (M).

John Bardeen

John Bardeen has been awarded the Medal of Honor "for his profound contributions to the understanding of the conductivity of solids, to the invention of the transistor, and to the microscopic theory of superconductivity."

Dr. Bardeen, who received the B.S. and M.S. degrees in electrical engineering from the University of Wisconsin in 1928 and 1929, has been interested mainly in the theory of solid-state and low-temperature physics, with emphasis on semiconductors and superconductivity.

Prior to his graduate studies at Princeton, where he received the Ph.D. degree in mathematical physics in 1936, Dr. Bardeen worked for several years with Gulf Research and Development Corporation as a geophysicist. Later he was a postdoctoral fellow at Harvard University, assistant professor of physics at the University of Minnesota, a physicist at the U.S. Naval Ordnance Laboratory during the war

# IMPORTANT ANNOUNCEMENT TO IEEE MEMBERS

In January, the IEEE Board of Directors authorized two steps to meet the current needs of the membership: reduced dues and fees for unemployed members, and arrangements for members to take part in legislative, employment, and retirement services under the auspices of the National Society of Professional Engineers.

**Unemployed members.** If you are currently unemployed through involuntary termination and are actively seeking reemployment, you may continue your IEEE membership through December 1971, with all privileges, publications, and services covered by membership dues (and by Group or Society fees, and subscription fees, if any) *by payment of one half of the established dues and fees.* If you wish to take advantage of this arrangement you must submit a signed statement to IEEE Headquarters that you are involuntarily unemployed and seeking reemployment. *No action to reduce the dues or to rebate payments already made can be taken until you notify Headquarters of your unemployed status.*

If the unemployment notification is received at Headquarters by February 28, 1971 (the established cutoff date for all members whose dues have not been paid), services will be continued without interruption. If it is not possible to meet that date, the unemployment notification can be accepted until July 1, 1971. Membership will be resumed when the notification is received and, upon request, publication services will be carried back to the first of the year, subject to availability of back issues.

When feasible, you can assist IEEE to reduce its costs by sending the one-half payment with your unemployment notification. If you do not submit the payment with your unemployment notification, IEEE will bill you for the half payment prior to the due date of July 1, 1971.

If you are unemployed and have already paid the full dues and fees for 1971, a rebate will be sent to you for the excess paid upon receipt of your unemployment notification and request for rebate.

To assure uninterrupted receipt of publications and services, members presently unemployed and desiring to accept the one-half payment arrangement should notify Headquarters at once, since services must be suspended on February 28, 1971, if your dues and fees have not been paid—unless we have knowledge of your unemployed status.

**NSPE services.** By special action of the IEEE and NSPE Boards of Directors, IEEE members wishing to take advantage of the services offered by the National Society of Professional Engineers may do so in a cooperative program. Full details of several optional plans will be provided in a later issue of SPECTRUM. Since membership in NSPE is no longer restricted to registered professional engineers and engineers-in-training, NSPE is open to qualified IEEE members who are not registered. In one of the options, IEEE members may subscribe at a special rate to NSPE publications and services without formal membership in NSPE. Included in this option are: bulletins, action reports, and opinion requests on current legislation; eligibility for the NSPE employment referral service; participation in the NSPE salary survey; and eligibility for the NSPE retirement programs.

By this cooperative effort, programs that cannot be offered by IEEE under its scientific, technical, and educational charter are available through NSPE, which is chartered to engage in legislative activities and economic programs.

John Simpson

Ernst Weber

years, and a research physicist at the Bell Telephone Laboratories from 1945 to 1951.

Dr. Bardeen assumed his present position at the University of Illinois in 1951. He is also currently a member of the Center for Advanced Study there.

A Fellow of the American Physical Society, Dr. Bardeen served as its president in 1968–1969. He is also a member of the National Academy of Sciences, the American Philosophical Society, and the American Academy of Arts and Sciences. He is on the board of directors of Xerox Corporation.

Dr. Bardeen, who has been the recipient of 16 various awards, was co-recipient of the Nobel Prize in Physics in 1956. Other honors and awards bestowed upon Dr. Bardeen include the National Medal of Science for 1965 and honorary doctor of science degrees from the University of Glasgow in 1967, Princeton University in 1968, and Rensselaer Polytechnic Institute in 1969.

John W. Simpson, recipient of the Edison Medal, has been honored "for his sustained contributions to society through the development and engineering design of nuclear power systems." President of Westinghouse Electric Corporation's Power Systems organization, Mr. Simpson holds a unique distinction in the development of the atom as a source of energy for mankind.

No other scientist is believed to have made as many significant contributions to all three pioneering applications of nuclear theory—marine propulsion, electric power generation, and space propulsion—as Mr. Simpson. He was in charge, for Westinghouse, of the design and construction of the nuclear propulsion plant for the *U.S.S. Nautilus*, the world's first atomic submarine. He also headed the team that designed and built the pressurized water reactor for the nation's first full-scale nuclear power plant in Shippingport, Pa.

Mr. Simpson was graduated from the United States Naval Academy with the B.S. degree in engineering. He joined Westinghouse in 1937 and, by studying during his free time, earned the master's degree in electrical engineering from the University of Pittsburgh in 1941.

Recipient of the Westinghouse Order of Merit, the company's highest award to its employees, Mr. Simpson was elected to the National Academy of Engineering in 1966. He is a member of the board of governors of the National Electrical Manufacturers Association and also serves as chairman of NEMA's Power Equipment Division.

Ernst Weber has received the Founders Award "for his leadership in the advancement of the electrical and electronics engineering profession in the fields of education, engineering societies, industry and government."

Born in Vienna, Austria, Dr. Weber pursued a double course of studies, attending both the Technical University of Vienna and the University of Vienna. He received the diploma in electrical engineering in 1924. He was awarded the Ph.D. from the University of Vienna in 1926 and the doctor of science degree from the Technical University in 1927.

Currently president emeritus of the Polytechnic Institute of Brooklyn, Dr. Weber has had a long association with the school. He was invited to be a visiting professor there in 1930. He was named a permanent research professor in charge of graduate study a year later.

Early in World War II, Dr. Weber organized a microwave research group, out of which grew the Microwave Research Institute. In recognition of these contributions, he was awarded the Presidential Certificate of Merit. In 1945 he was appointed head of the Department of Electrical Engineering and director of the Microwave Research Institute. Under Dr. Weber's direction the electrical engineering enrollment grew to be 38 percent of the MRI's total enrollment.

Dr. Weber was named vice president for research in 1957 and later that same year president of MRI. He retired as president in June 1969.

Now serving as chairman of the Engineering Division of the National Research Council, National Academy of Sciences, Washington, D.C., Dr. Weber is a member of the advisory group to the Army Electronics Command and a member of New York Governor Rockefeller's Advisory Council for the Advancement of Industrial Research and Development.

Dr. Weber was a Fellow of the Institute of Radio Engineers and served as its president in 1959. He was also the first President of the IEEE in 1963. He holds honorary doctorates from Newark College of Engineering, Pratt Institute, Brooklyn Law School, Long Island University, and the University of Michigan.

Winthrop M. Leeds has received the Lamme Medal "for contributions to the development of high voltage, high power circuit breakers, specifically using SF6 gas, and for his effective exposition of the theory of arc interruption."

W. M. Leeds

F. Ollendorff

A recently retired consulting engineer with the Power Circuit Breaker Division of Westinghouse Corporation, where he had been employed for 43 years, Dr. Leeds received the B.S. degree from Haverford College in 1926 and the M.S. degree in electrical engineering from the University of Pittsburgh in 1930. From 1937 to 1938 Dr. Leeds attended M.I.T. on a Lamme Scholarship. He received the Ph.D. in physics and engineering from the University of Pittsburgh in 1945.

During his career at Westinghouse, Dr. Leeds worked as a design engineer, as consultant engineer, and as manager of circuit breaker development, switchgear long-range development, power circuit breaker engineering, and new products engineering. He has spent much of his time in switchgear development and participated in the development of all types of air, oil, and sulfurhexafluoride high-voltage circuit breakers.

Holder of 90 patents, with seven patents pending, Dr. Leeds has been cited as "ranking fourth at Westinghouse in total patents issued to an individual inventor among active employees." Dr. Leeds is author of 33 technical articles or papers, of which 19 are *IEEE Transactions* papers, including a national prize paper and a District prize paper.

Franz C. Ollendorff, IEEE Education Medal recipient, has been honored for his "contributions to the teaching of electrical engineering, especially the preparation of classic texts on electromagnetic fields, and for leadership in building a distinguished program in a new institute."

Born in Berlin, Germany, Dr. Ollendorff was graduated from the Berlin-Charlottenburg Technische Hochschule as Diplomingenieur in electrical power engineering. A year later he received the doctorate at the Danzig Technische Hochschule. After receiving the doctorate Dr. Ollendorff worked for 11 years in technological research at the two schools.

Discharged by the Nazi Government at the age of 33, Dr. Ollendorff temporarily abandoned his scientific activity and devoted his time to the education and rescue of Jewish school children.

In 1937 he joined the teaching staff of the Technion and its vocational high school. He became professor of electrical engineering and physical electronics and then research professor in 1955. Currently, he holds the Gerard Swope Chair of Electrical Engineering.

Author of a large number of scientific papers covering all fields of modern electrotechnology, Dr. Ollendorff is presently devoting his efforts mainly to the development of medical engineering. He is also planning a comprehensive investigation dealing with the humanitarian aspects of modern technology.

Andrew H. Bobeck, Robert F. Fischer, Anthony J. Perneski, Joseph P. Remeika, and L. G. Van Uitert, all coauthors, have received the W. R. G. Baker Prize Award for their paper entitled "Application of Orthoferrites to Domain-Wall Devices." The paper appeared in the *IEEE Transactions on Magnetics*, vol. MAG-5, no. 3, September 1969.

All the men are on the technical staff at Bell Telephone Laboratories.

Mr. Bobeck, who received the B.S. and M.S. degrees from Purdue University, has specialized in the development of magnetic logic and memory devices. He was responsible for the conception and development of the twistor memory device. Recently he has been involved in the investigation of the properties of cylindrical domains found in uniaxial magnetic materials such as the orthoferrites.

After graduating from the U.S. Navy Electronic Technician School and serving as an electronic technician in the Navy for two years, Mr. Fischer joined Bell Labs and worked on magnetic logic devices. He was involved with the design of magnetic memory module test equipment. He is currently concerned with domain wall devices.

Anthony Perneski received the B.S. degree from Pennsylvania State University in 1961 and the M.E.E. degree from New York University in 1963. He joined the Bell System's Fundamental Memory Components Department in 1961. Most recently he has been working on orthoferrite devices.

Mr. Remeika, a member of the Solid-State and Physics of Metals Research Department at Bell Labs, is engaged in research in solid-state chemistry aimed toward discovering new magnetic, dielectric, and semiconductor materials. Author or coauthur of over 100 articles, Mr. Remeika has been granted about 20 patents.

Dr. Van Uitert received the B.S. degree from George Washington University in 1949 and the Ph.D. degree in chemistry from Pennsylvania State University in 1952. Since joining Bell Labs in that year, Dr. Van Uitert has made significant contributions in the fields of microwave ferrites and garnets, ferroelectrics, solid-state lasers, nonlinear optics, acoustooptics, luminescence, and the Czochralski and flux growth of crystals.

Lloyd J. Griffiths has received the Browder J. Thompson Memorial Prize for his paper "A Simple Adaptive Algorithm for Real-Time Processing in Antenna Arrays." This appeared in the *Proceedings of the IEEE*, vol. 57, no. 10, October 1969. Dr. Griffiths, born in Edmonton, Alta., Canada, received the B.S. degree from the University of Alberta in 1963. He received the M.S. and Ph.D. degrees from Stanford University in 1965 and 1968.

In 1968 he joined the faculty of the Electrical Engineering Department at the University of Colorado in Boulder. He spent 1969 as staff scientist for the Barry Research Corporation in Palo Alto, Calif., where he worked on a variety of high-frequency radio wave propagation and signal processing problems.

In the fall of 1970 Dr. Griffiths returned to the University of Colorado, where his teaching and research interests pertain to statistical communication theory as applied to radio communication and radar problems, including array processing and spectrum utilization.

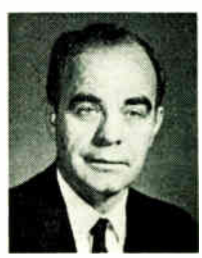
A. Bobeck

R. Fischer

A. Perneski

J. Remeika

L. Van Uitert



L. Griffiths